PRODUCT ENGINEERING

APRIL, 1944

In this Issue: **ALUMINUM,** A 16-page Special Section

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Subscribers may encounter delay in receiving their copies of PRODUCT ENGINEERING. Such delay is caused by wartime strain on transportation and postal systems, a situation beyond the Publisher's control.

IN THIS ISSUE

Cover Picture

LST (landing ship tank) in practice maneuvers. Kodachrome courtesy Photographic Section, U. S. Navy.

British Aircraft Program Features Interchangeability

Britain takes full advantage of interchangeability in aircraft components. Under direction of the Ministry of Aircraft Production, the program operates smoothly from the time the first designs are made to the finished plane. Rapid repair of action-damaged planes can be made at points removed from repair depots. Details of the interchangeability program are presented on page 217 with a folded page devoted to interchangeable components of the Lancaster Bomber.

Special Section: Aluminum

Wartime applications of aluminum and its alloys, and increased experience in the fabrication of these materials,

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have been a stimulus for more extensive post-war applications. New high strength alloys and improved technique in such fabricating methods as welding and forming of sheet aluminum have been particularly significant in airplane manufacture. Starting on page 253 a 16-page special section presents the distinguishing characteristics of aluminum, methods of fabrication, and illustrates many applications.

Induction Heating From Design Viewpoint

The advantages of using induction heating will create new designing techniques in the opinion of Frank W. Curtis of the Induction Heating Corporation. He presents his views and demonstrates various examples of induction heating technique in an article on page 242. While maximum effectiveness and efficiency of high-frequency heating can be obtained if the original design takes this method into consideration, designs can be modified, often just slightly, to take advantage of the induction heating process.

Anti-Friction Bearings For Varying Loads

The easiest way to select an anti-friction bearing is to use the least or the simplest mathematics. In applications where the loads carried by the bearings vary over a considerable range this method does not give as accurate an estimate of bearing life as might be desired. A bearing large enough to carry the peak load continuously is larger than necessary and one based on an arithmetical average of loads is apt to be too small. Kenneth N. Mills illustrates on page 250 the application of formulas for more accurate selection of bearings in this type of service by carrying through the computations for a hoisting machine for removing pipe from an oil well. He also outlines the general considerations in selecting anti-friction bearings.

Safety Considerations For Production Machinery

The role design engineers can play in reducing accidents on production lines is stressed by Frederic L. Stafford, safety engineer, in an article on page 248. Incorporation of safety features in the original design of production machinery is regarded as a potent factor in eliminating needless accidents to machine operators. Improvised guards are viewed as potential hazards.

Weight and Stress Analysis Of Monocoque-Type Fuselage

As a sequel to "Truss-Type Fuselage Analysis With Graphical Solutions" which was presented in the March number of PRODUCT ENGINEERING, Gail Swan, chief of structures, Kaiser Cargo, Inc., Fleetwings Division, describes a well tested method of procedure, see page 272, for distributing weight items and for calculating bending moments, shears and stresses in monocoque and semi-monocoque fuselages.

Design for Plastics

Variations in materials, fillers, processing methods and design techniques all affect the performance and service characteristics of molded plastic parts. For most efficient design with plastics the engineer must take these variables into account when specifying the material or processing method or when laying out the part. As a guide for General Electric Company engineers W. S. Larson, of the Plastics Department, has collected a wealth of fundamental information on selection and design of plastic parts. On page 225 appears the first article in a series based on this collection of data.

Deflections and Chatter In Machine Tools

In the coming post-war era many new machines will be designed. Those who will do that job will be interested in this discussion of the practical application of the laws of deflection as applied to machine tools. George E. Hieber, design engineer, Landis Machine Company, see page 269, relates some of his experience in the field of machine tool design and the troubles that may be encountered if sufficient attention is not given to the effects of accumulated deflections in an assembly of moving parts.

Pneumatic Circuits And Typical Applications

Compressed air circuits have found a wide variety of applications in machine operation. They offer the advantages of cleanliness and nonhazardous operation and control. Air pressure, speed of operation, cycle of operations, and general conditions are considered in design of circuits. Possible applications are too numerous to illustrate adequately but some idea of their scope may be gained from the layouts shown on page 246.

Reproducing Templates By After-Glow

Newest of the various means for reproducing templates, the after-glow technique already has several variations. The most prominent of these are described briefly in the article beginning on page 276. This is the fourth in a series covering all methods of template reproduction now in use. The series is based on a comprehensive survey made by Thomas Miles, reproduction supervisor for Consolidated Vultee Aircraft Corporation.

Plate Diameters For Formed Domes and Heads

Equations or formulas are given for calculating the diameters of plate or sheet-metal blanks that are to be formed into domes and heads. The formulas as set forth by Joel Eklund, see page 287, can be applied to a great number of parts ranging from small metal cups to domes for large cylindrical vessels.

WHAT'S COMING

Precision Castings

Castings of high dimensional accuracy are now being produced for war equipment by an industrial adaptation of dental and jewelry casting technique, sometimes known as the "lost-wax" process. Under government and private research, applications are being extended to utilize many types of materials, including steel. In a forthcoming issue, a comprehensive analysis of this new process will be presented. Included will be a brief description of the process, its advantages and recommended materials, illustrations of typical applications with discussion of engineering features, mechanical properties and service advantages.

Effect of Clearance on Bearing Performance

Prediction of bearing performance involves numerous theoretical considerations along with complicated equations. In an article scheduled for May, L. M. Tichvinsky, U. S. Naval Engineering Experiment Station, analyzes clearance ratios and their use as a design factor. Lower and upper clearance limits are discussed with regard to their effect on bearing performance. The article includes bearing clearance data for various types of machinery and a suggested method for clearance measurement.

PRODUCT ENGINEERING
APRIL, 1944

Proud symbol of Canada's remarkable technical development during this war, the Lancaster is equal in size to the Liberator or Fortress but all of its more than 100 components are completely interchangeable with those manufactured in English plants.

British Augment Air Power Through Interchangeability Program

Lancaster four-motor bombers are being produced by Victory Aircraft Limited, Malton, Ontario, within the framework of a plan established by the British Ministry of Aircraft Production to insure complete interchangeability of components, regardless of source. Engineering features behind the program are described.

FEW American engineers realize that they have been outdistanced in applying a Yankee invention—interchangeable manufacture—to aircraft construction. For within the limits of the specific design, and the technical ability of the designing firm, each British aircraft is fully interchangeable with respect to its components, regardless of source of manufacture.

This situation is not an accident. From experience in World War I and her strategic situation prior to this conflict, England developed a policy that entrusts aircraft interchangeability to the hands of the Ministry of Aircraft Production. Whenever the RAF wants a new operational type, the specifications are handed to a selected prime contractor. One contract provides for the engineering work and production of a stipulated number of airplanes. A feature of this contract is that with the sixth and subsequent production-built planes, the components must be fully interchangeable, likewise spares. A separate contract provides for the development of an interchangeability schedule and the design and building of all necessary interchangeability media—gages and jig references—in sufficient quantity to regulate the quality of components produced at all plants involved. Title to the interchangeability media remains in the hands of M.A.P., which maintains a resident interchangeability inspector specialist at each plant working on the program.

England embarked upon the inter-

changeability idea because of strategic reasons, but the program has engineering and manufacturing advantages too. The government realized: (1) Because of vulnerability to bomber attack from the Continent, the manufacture of aircraft would best be handled by the shadow-plant program, wherein there are always several sources for any component, and (2) the RAF might be forced to fight on many distant fronts and must be supplied with spares to salvage worn or damaged planes, either at a base or in open country, with a minimum of delay and without the use of special tooling and skills.

Both circumstances pointed to the necessity for making the components in easily transportable pieces—by road, rail, sea or air. For this reason the Lancaster four-motor bomber (now made in Canada by Victory Aircraft Ltd. as well as in England by several companies) consists of over 100 components. And the components produced in all plants are fully interchangeable. The largest of these is the centerplane (center wing and part of the fuselage) but it measures only 30 ft. between attachment points for the outer wings.

For ease of replacement, all components are assembled with bolts or screws. A fuselage section, for example, can be replaced in two hours. It comes complete with all piping, electrical wiring and rigging cables passing through that particular portion of the ship, and these lines are merely connected to the balance of the systems with couplings or unions. And because the bolt holes in the end frames or formers have been drilled on drill-referenced jigs, it is necessary only to align the fuselage sections and slip close fitting bolts in several scores of holes.

The Lancaster is as large as the Liberator or Fortress but its components are more easily transported. It is reliably stated that repairs can be made more promptly and that the tooling problems for the larger units, such as fuselage and wings, are not as difficult because of sectionalized construction.

In addition, the British do not impose upon themselves the troubles incidental to attempting precise relationship between all features—attachment points—found in a large structure. In the Lancaster centerplane there are a number of features, but no attempt is made, for example, precisely to relate the location of the outer-wing attachments to the engine-mount attachments. A fairly generous tolerance is permissible between these sets of attachments. Some American designers do attempt this sort of thing even though the center-wing section may be considerably larger, with a consequent increase in gaging difficulties. But it cannot be said that the English condone poor workmanship or sacrifice of aerodynamic efficiency because the maximum variation in rigging angles, from wing tip to wing tip, is maintained within close limits.

Manufacturing Advantages

The manufacturing advantages of the British system are as follows: First, components arrive at the final assembly line with all installations complete so far as possible. This means that the final assembly floor occupies minimum space. One plant has room on its final assembly line for only a few days' production; second, less labor is required at assembly because interchangeability is controlled in the jigs by the interchangeability media. Jigs are smaller and therefore they can be moved readily.

Interchangeability becomes a factor in design of British aircraft immediately following government approval of the artist's sketch for a new model. Decisions must be made at this stage concerning the physical size of the components, not only to achieve sections of transportable size but ones that lend themselves to being carried as spares by RAF depots. Obviously sectionalized construction of the fuselage and wings requires the designer to pay special attention to the strength of the attachments and any necessary modifications in structural elements, to cope with the effect of landing shock, bomb load, fuel weight, engine thrust. Any additional weight that may ensue is considered worthwhile because of the speed with which the component can be replaced in the field.

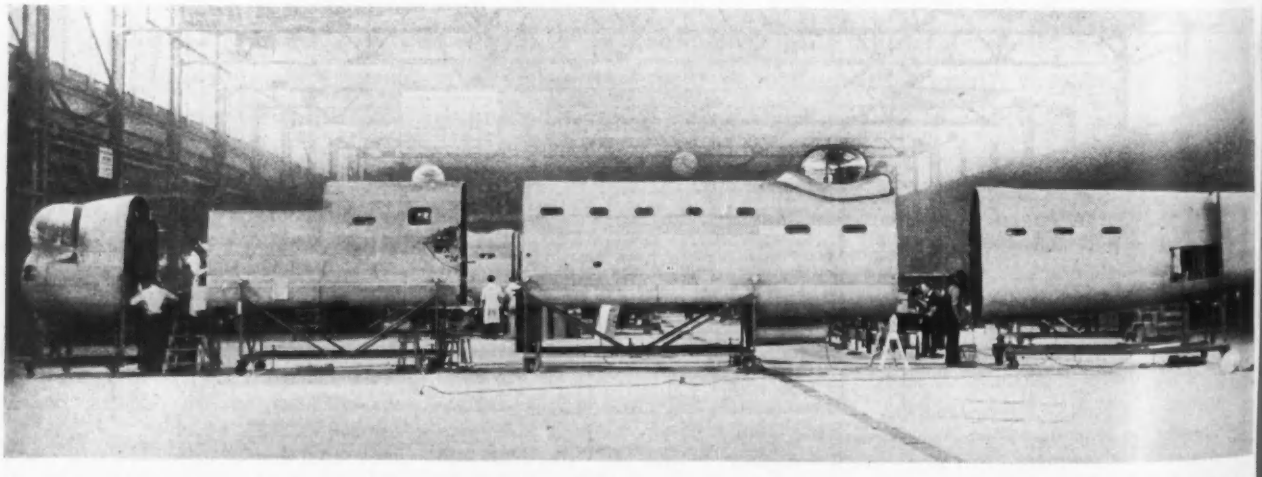
A chart is prepared showing all of the main components, relating each part with its counterpart. This is the first stage in preparing the interchangeability scheme. The designing firm employs interchangeability experts in its engineering section. These men are conversant with shop practice and permissible tolerances in aircraft work. Field reports assist their judgment. As detailers progress with the design of a part and its counterpart, the interchangeability section not only advises the engineering section but prepares data sheets bearing only a line drawing of part and counterpart in juxtaposition and significant dimensions, tolerances and clearances.

The interchangeability data sheets are subject to the approval of the Ministry of Aircraft Production. These sheets serve the following purposes, and become a permanent record.

1. To focus attention immediately upon inconsistencies and unpractical aspects of the design from shop and service standpoints.

2. To provide essential information, without cluttering detail, to the tool designer.

3. To relate all information necessary



Strategic and practical advantages of interchangeability are the ease with which components are assembled, either at the plant or at RAF stations. All components of the Lancaster are fastened with either close-fitting bolts or screws, which are expected to assemble components without line-reaming the bolt holes in mating components. Fuselage sections are merely placed on dollies for mating.

for design and procurement of the interchangeability media—jig references, drill references and gages—that control quality of manufacture.

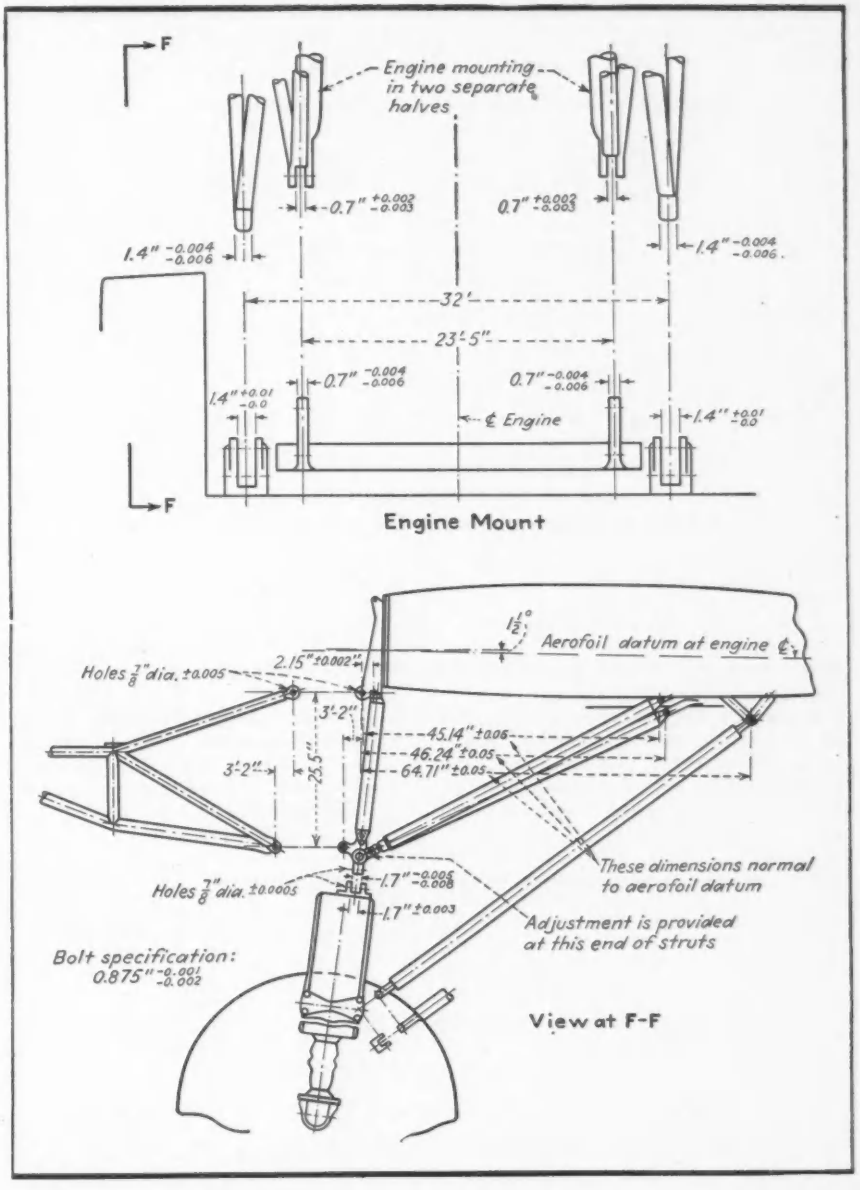
The preparation and approval of an interchangeability schedule does not appreciably delay the actual tool design program and any time lost initially is made up by reducing the "bugs" that must be worked out when the ship goes into production. Obviously the tooling program is not delayed until the entire interchangeability schedule is approved by M.A.P. For as fast as the details are finished for a part and counterpart, tool design can take over. Design of the interchangeability media can likewise proceed.

The time interval between building the prototype aircraft and the sixth production plane is purposely allowed by M.A.P. for perfection of the interchangeability schedule, media and jigs. Thereafter, until modifications enter the picture, all components must be fully interchangeable. And because modifications do have important effects upon the interchangeability system, they are not imposed at will. As with the American Air Forces, certain classes of modifications must be made immediately, and operational flying ceases until they are accomplished. Then there are additional types of modifications that are entrusted to modification centers. Other modifications are made by the component manufacturer at stated intervals in production of a series.

More should be said about tolerances. For shafts and holes the British engineer finds satisfactory either the Newall system or that proposed by the Institute of Production Engineers. Specifications of tolerances for mating parts is another matter, and careful checking is essential. The following considerations govern the design of mating parts.

In the design of aircraft structures, it is essential that all governing dimensions be related to a common origin, or datum line. Then to insure interchangeability, the design of the part and the counterpart must be such that—in all positions possible within the permitted tolerances—the envelope of each male feature (usually an attachment point) will fall within the internal envelope of the associated female feature. Therefore, tolerances on dimensions locating the features with reference to the datum line must be considered in relation to the maximum and minimum tolerances applied to the features.

The location of the datum line for a part and counterpart is an important matter, for it can increase or decrease the gagemaker's troubles. It is customary in England for gagemakers to work to one-tenth of the tolerance allowed on the component.



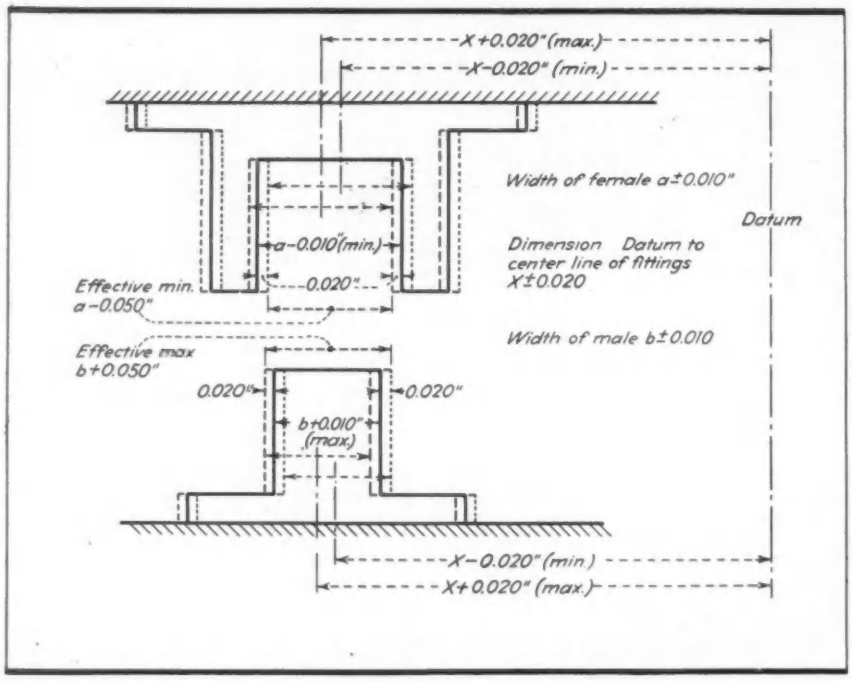
Interchangeability data sheets are prepared to show each part in juxtaposition with its counterpart. Only the dimensions, tolerances and clearances essential to maintain interchangeability are transferred to these sheets from the working drawings. The sheets promote immediate correction of unpractical aspects of the design, from the shop or service standpoints, and provide in compact form the essential information for design of jigs and interchangeability media—drill references, gages, jig references. The sheet shown is for a two-motor bomber but depicts the principle followed.

Generous clearances should be applied to attachments, consistent with strength and aerodynamic efficiency. But clearances can be applied rightly and wrongly. Consider for example the attachment of a stabilizer to the fuselage with bolts through boundary-angle fittings. A clearance of 0.010 in. could be provided in all bolt holes with the hope that variations in hole spacing would cause some of the bolts to bear and so take the shear load. Better practice, in English eyes, is to specify two or more accurately reamed holes for "fitted" bolts at suitable spacing, and provide say $\frac{1}{32}$ in. clearance for the remaining bolts. Of course this practice requires the use of referenced drill jigs, which will be explained later.

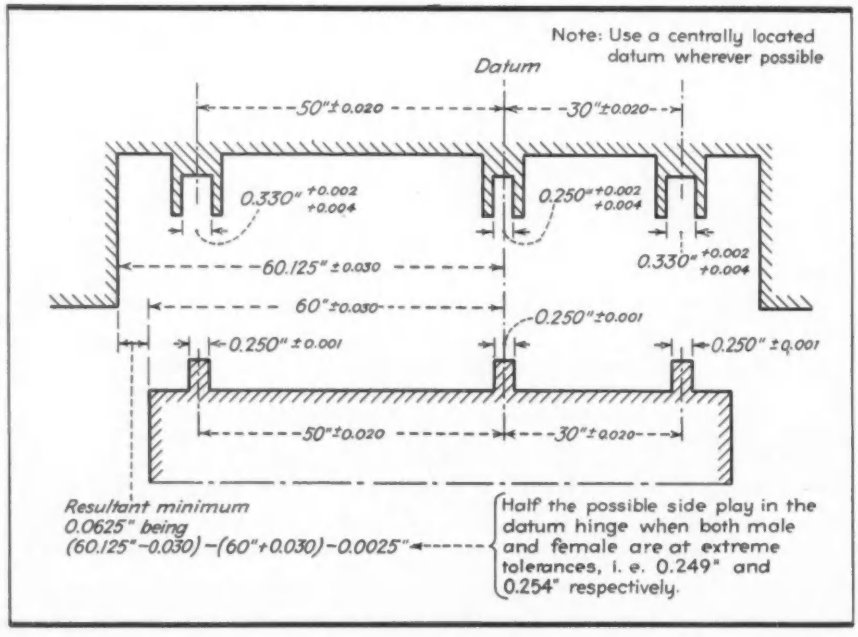
Close Fits Essential

Close-fitting bolts are even more important for attachments subject to vibration and alternating stresses, and must be assembled to extremely close rigging angles. If there is any looseness, rapidly reversing stresses imposed upon the attachments will cause the bolt holes to elongate or the bolts to wear from the hammering action.

A prime example of this is the at-



In design of attachments for aircraft assemblies, which are checked by gaging, dimensions are related to a datum line. Then to insure proper clearance of attachments of part and counterpart, tolerances are set so that the envelope of the male attachment in all possible positions will fall within the internal envelope of the associated female feature. Thus dimension a—0.050 in. must be greater than b+0.050 in.



In multiple-hinge connections it is advisable to select a central hinge as the datum to minimize side play and give the gagemaker and the shop the advantage of a tolerance applied to a shorter dimension, in this case 50 in. instead of 60 in.

tachment of the outer wing to the centerplane. As shown by an accompanying sketch, four attachments on the center plane fall at the corner of a rectangle measuring approximately 26x90 in. The holes must not deviate from common centerlines by more than 0.001 in. if aerodynamic efficiency of the plane is to be maintained. And bolt holes in the mating attachments of the outer wing are likewise located with the same degree of accuracy. The bolt holes in the attachments of both components are reamed and honed in their respective assembly jigs after all riveting has been completed and the clamping pressure is released. When the mating attachments are brought together at final assembly, bolts with a clearance of only 0.0005 in. can be slipped in place.

That circumstance can be considered a remarkable achievement, considering the fact that the centerplane is 30 ft. long, and each outer wing is nearly as long. But it is necessary if the structure is not to be sprung at final assembly, thereby destroying the interchangeability of components, and imposing additional stresses on the structure.

Interchangeability Media

Thus it will be seen that in developing true interchangeability for all components of an aircraft, including large riveted and welded structures, the designer must appraise the interchangeability problems of the various components and be familiar with the media by which the shop can realize the desired degree of quality. Components can be divided into four classes:

1. Machined parts, sheet-metal details and hardware.

2. Piping, control cables, seats, landing-gear shock struts, gun mountings and similar sub-assemblies.

3. Bomb doors, detachable fuel tanks, skin components, pilot's enclosure, and similar more complex sub-assemblies.

4. Structural components such as fuselage sections, outer wings, centerplane, ailerons, flaps, rudders, stabilizers, landing gears, engine mounts.

Components in Class 1 present no serious interchangeability problems, and Class II items are easily produced in simple jigs or gaged.

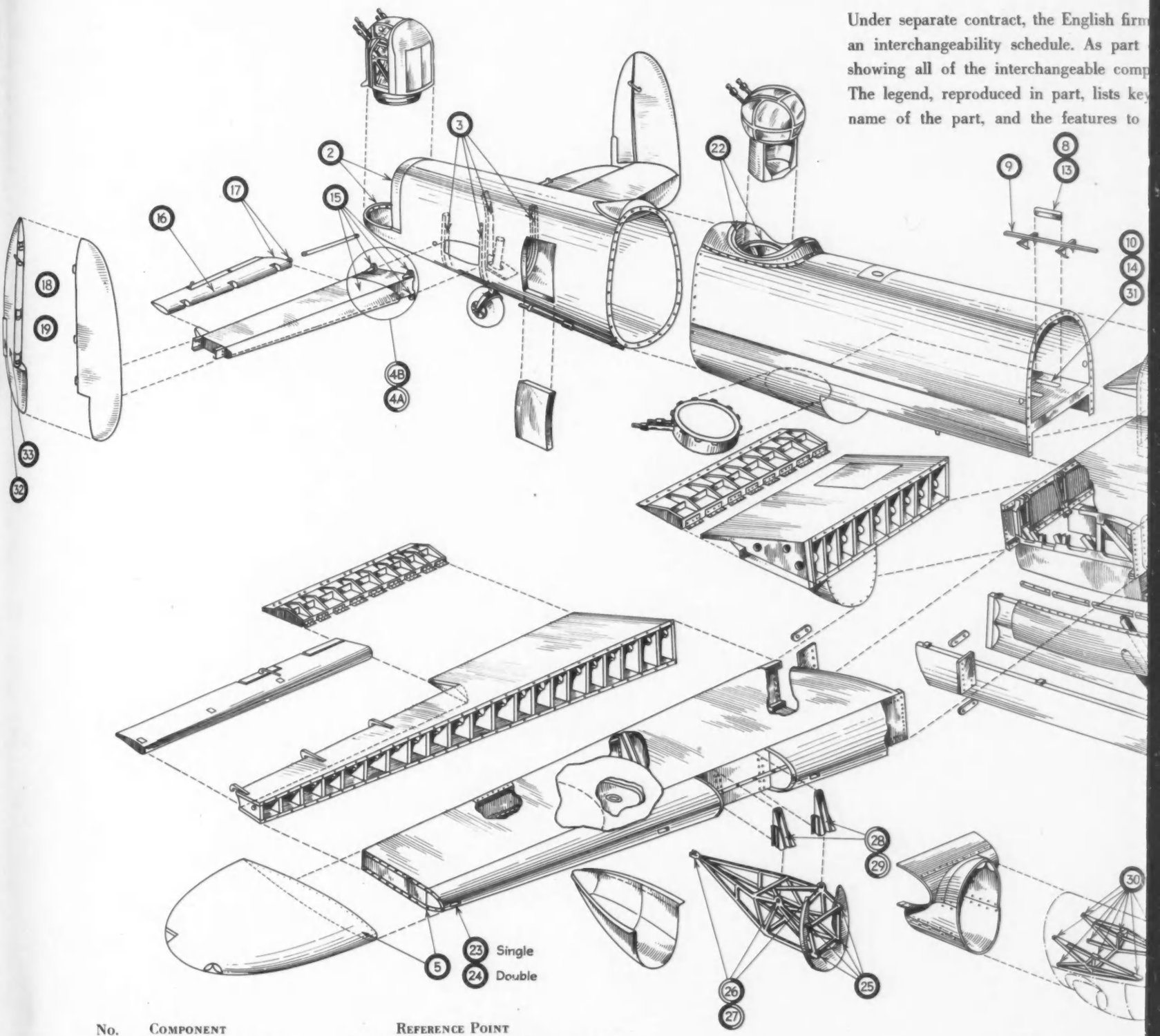
Accurate jigs, checked periodically with "references," are needed in production of Class III items.

The complexity of attachments, and the virtual absence or smallness of tolerances for attachments, of components in Class IV give rise to difficult problems in maintaining interchangeability. Sometimes it is practicable to gage the components, but frequently the use of jig references is required.

Therefore during the design of a new aircraft the British engineer keeps in the front of his mind the various types of interchangeability media available for checking the component. These are:

1. Drill references. These are masters from which production drill jigs are drilled, reamed, bushed and inspected. In the case of spars and other members over 10 ft. long, and where limits on essential dimensions are very exacting, the drill references and the drill jigs are made of duralumin to compensate for temperature changes. This practice avoids parts that will not fit: Differential expansion of a 30-ft. dural spar in a steel jig amounts to 0.046 in. between

Under separate contract, the English firm
an interchangeability schedule. As part
showing all of the interchangeable comp
The legend, reproduced in part, lists ke
name of the part, and the features to

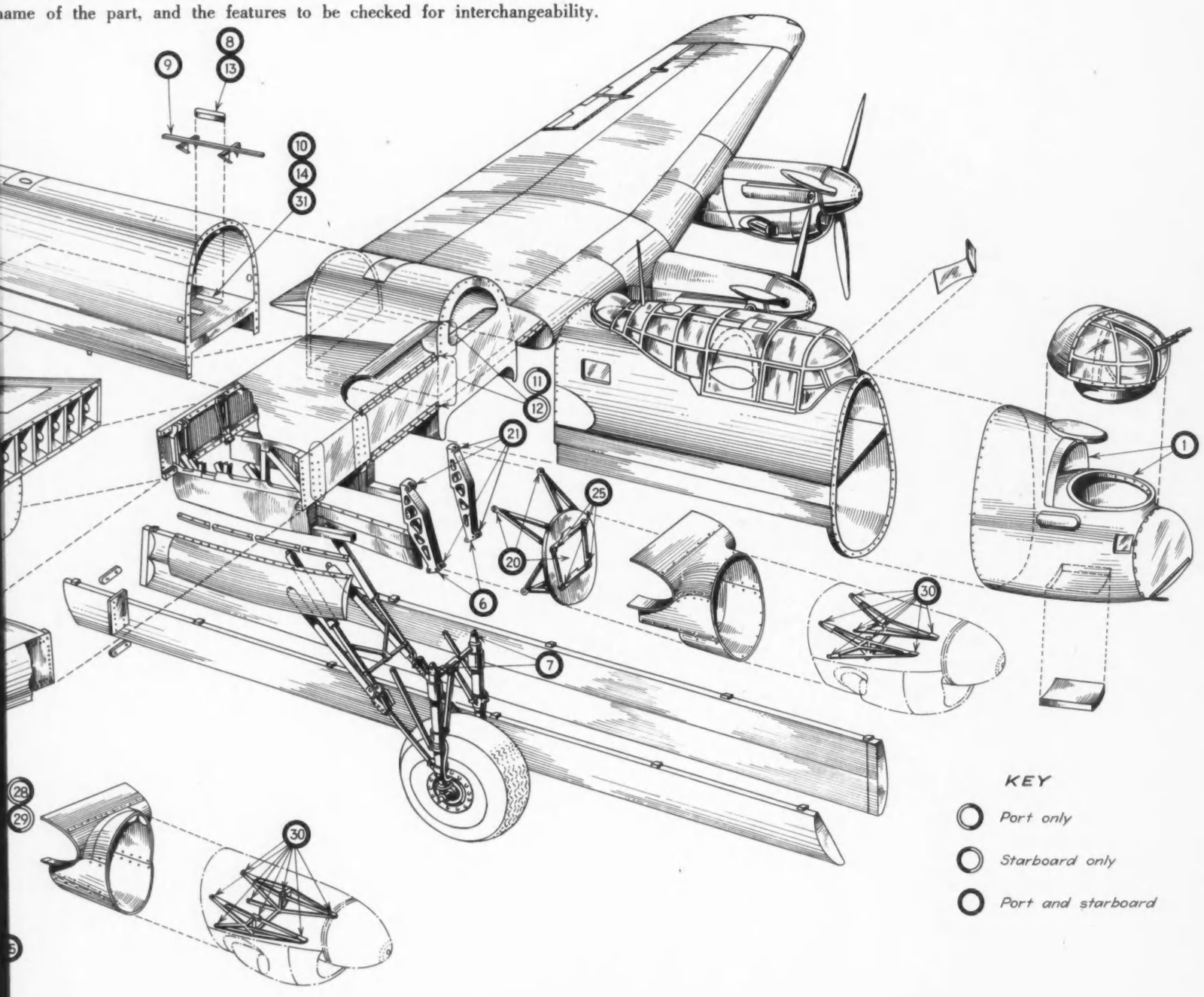


No.	Component	Reference Point
1	Fuselage nose section	Attachments and clearance for turret
2	Fuselage rear section	Attachments and clearance for turret
3	Fuselage rear section	Attachments and clearances for tail planes
4	Tailplane	Attachments and clearances for fuselage
5	Outer wings to wing tip	Attachments for wing tip joint
6	Undercarriage support beams	Attachments for undercarriage
7	Undercarriage	Attachments for support beams
8	Bomb housing, 500 and 2,000 lb.	Attachments for floor and carrier
9	Bomb carrier, 500 or 2,000 lb.	Attachments for bomb housing
10	Main floors	Attachments for 2,000 lb. bomb housing
11	Leading edge and front spar (port)	Top hinges and bottom fasteners
12	(starboard)	Top hinges and bottom fasteners

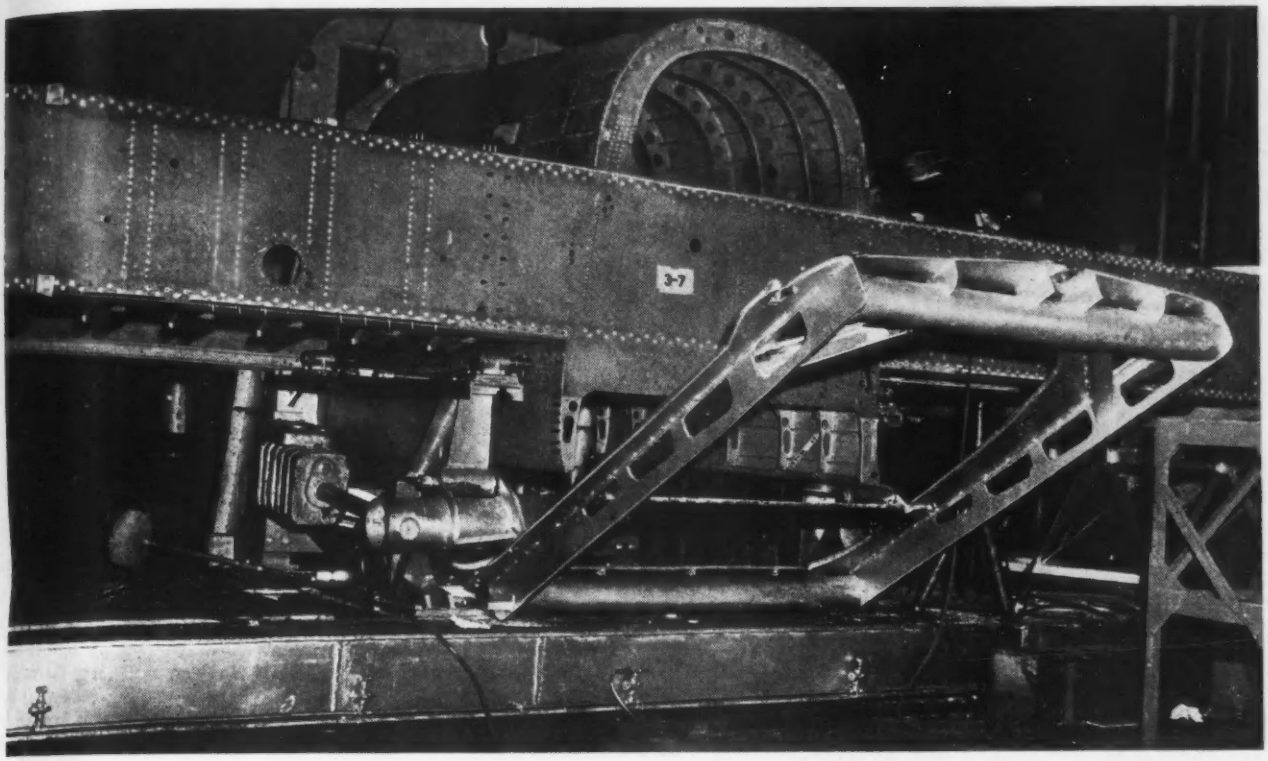
No.	Component	Reference Point
13	500 lb. bomb housing	Attachments for floor and ca
14	Center section floor	Attachments for 500 lb. bon
15	Tailplane	Attachments port to starboar
16	Elevator	Hinges and swing clearance
17	Elevator	Torque tube attachment hol
18	Rudder	Hinges and swing clearance f
19	Fin	Hinges and swing clearance
20	Inboard engine sub-frame	Attachments for undercarria beams
21	Undercarriage support beams	Attachments for inboard sul
22	Fuselage rear center section	Attachments and clearances
23	Single CC container	Profile and aperture

EABLE COMPONENTS OF THE LANCASTER BOMBER

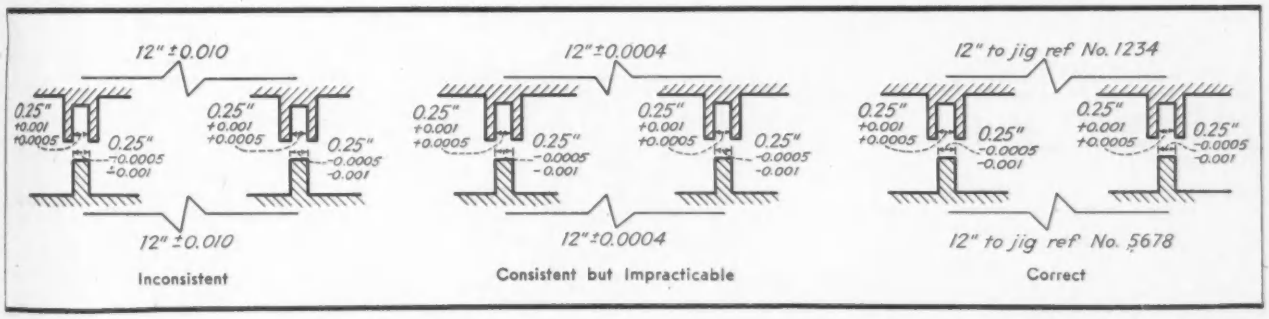
Under separate contract, the English firm designing a new aircraft prepares an interchangeability schedule. As part of this work a sketch is prepared showing all of the interchangeable components in relation to one another. The legend, reproduced in part, lists key numbers for the components, the name of the part, and the features to be checked for interchangeability.



No.	Component	Reference Point
		Attachments for floor and carrier
		Attachments for 500 lb. bomb housing
		Attachments port to starboard half
		Hinges and swing clearance
		Torque tube attachment holes
		Hinges and swing clearance for fin
		Hinges and swing clearance for rudder
		Attachments for undercarriage support beams
		Attachments for inboard sub-frame
		Attachments and clearances upper turret
		Profile and aperture
24	Double CC container	Profile and aperture
25	Engine sub frames	Attachments for engine mounting
26	Outboard engine sub-frame (port)	Attachments for center wing channels
27	(starboard)	Attachments for center wing channels
28	Outer wing (port)	Attachments for sub-frame
29	Outer wing (starboard)	Attachments for sub-frame
30	Merlin engine mounting	Attachments for sub-frame
31	Front and rear center section floor	Attachments for 2,000 lb. carrier
32	Rudder trimmer	Hinges and over-all length
33	Rudder	Attachments and clearances for trimmer



Large structures like the Lancaster centerplane may have several groups of pick-up points—for the outer wings, landing gear, fuselage section, and so on. Very small tolerances may be required within a specified group of pick-up points, but appreciable tolerances apply between distinct groups of points. For this reason, the British apply jig references individually to each group of points, and establish the correct relationship of the various references by optical instruments and Johannson inside micrometers. This practice avoids jig references so cumbersome it is doubtful that interchangeability of components will actually be achieved.



Attachment fittings between part and counterpart must often mate with such fine clearances that the locating dimensions and alignment must be held to tolerances impracticable by any other method than precision jigging. No attempt in such cases should be made to define permissible tolerances on working drawings. Instead the nominal dimension should be noted "To jig reference . . ." quoting the serial number of the jig reference concerned. The interchangeability section decides the type of reference required.

60 and 80 deg. F. factory temperature.

The Dural drill plates float on a steel bed. Later in the assembly fixture the drilled spar is picked up by a fixed point at one end (usually the inboard end) and by floating points at intermediate stations.

2. Mechanical jig references that check jigs, not components. These are commonly used for large sub-assemblies that are too bulky or heavy for gaging and involve close tolerances. Jig references are castings, sometimes made from scrap aluminum but most frequently of cast iron to avoid damage. The castings are machined for pick-up fittings, and for leveling and measuring surfaces that are located as closely as the gagemaker can work, in contrast to the aforementioned gages which are commonly made to one-tenth the tolerance allowed on the working drawing.

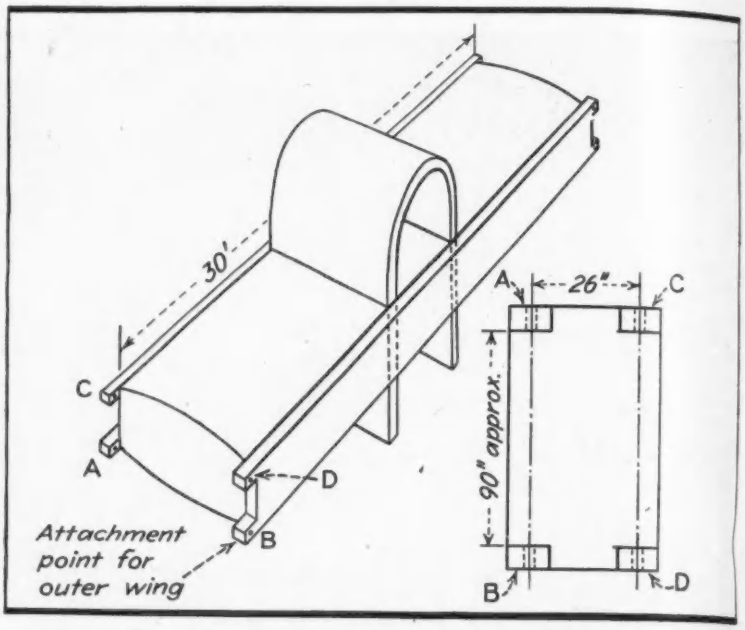
Jig references have these advantages:

(a) Assembly jigs in which pick-up points and locating surfaces are accurately set to the jig reference produce components that assemble without fitting. For example, fin-attachment holes in the front and rear spars of the tailplane are jig-referenced. Corresponding attachment holes in the fins are referenced with counterparts of the tailplane-spar jig reference. The holes in the two parts are reamed in their respective assembly jigs, but close-fitting bolts will assemble the two components without further fitting operations.

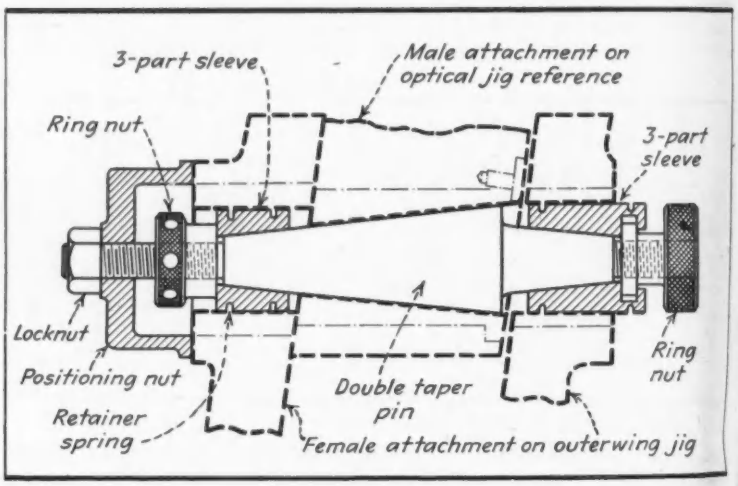
(b) The jig reference for a part can be set and checked with the jig reference of the counterpart, something that is impossible with the gages for the two parts. Furthermore, when a male reference is produced it can be employed as the master pattern when making the female.

3. Optical jig references. For setting up and periodic checking of large assembly jigs, in which utmost precision

An optical reference is being attached to wing-spar pick-ups at one corner of the centerplane jig. Because of the precision with which the reference is made and the use of a special mounting pin to insure exact location, it is possible with optical alignment apparatus to detect displacement of similar pickups 30 ft. away within 0.001 in.; to 0.0002 in. at 5 ft.



Tolerances for location of the bolt holes in the outerwing attachments of the center-plane are practically non-existent so far as ordinary gaging means are concerned. To maintain aerodynamic efficiency, hole A *must not lie more than 0.001 in. to the left of the center line, nor hole* B *the same amount to the right of the center line. Similar conditions apply to holes* C *and* D. *Axes of these holes must fall in a plane parallel to the plane containing attachment-holes axes at the other end of the component some 30 ft. away.*



A double-cone pin and two split rings, or collets, positions each male attachment of the optical jig reference in the female jig references permanently mounted on the centerplane jig.

is required at widely separated attachment points (components such as the centerplane and the outer wings) optical jig references have been brought to a high state of development in England. Furthermore they are now being made in Canada.

Optical reference equipment consists of: (1) Optical alignment apparatus developed by Taylor, Taylor & Hobson, Ltd., Leicester, England; (2) ultra-precision jig references that attach to the jig pick-ups, or attachment points, and which mount the alignment telescope and collimator; and (3) English-type Johannson micrometer trammels, or sectionalized inside micrometers.

Optical jig references will detect misalignment of 0.010 in. at 50 ft., lack of parallelism within six seconds of arc (one part in 30,000). The mounting brackets of the references incorporate trammel pads that are held to a total tolerance of 0.0002 in. with respect to the axis of the attachment holes fitting the pick-ups in the jig. With the micrometer trammels, it is possible to measure within 0.005 in. between trammel pads spaced 30 ft. apart; to within 0.0002 in. in a 5-ft. distance.

4. Gages that check the component. These are used for small parts, sub-assemblies and assemblies possessing sufficiently wide tolerances. Lightness with adequate rigidity are necessary features of such gages. Tubular-steel framework is commonly employed for the gage structure in order to achieve rigidity. Cast-iron brackets support non-adjustable locating pads or bushing plates. If deflection or wear occurs, the gaging elements must be remachined—no shimming is permitted. Weight permitting, gages for parts and assemblies under 15 ft. long are taken to the component; otherwise, the part is taken to the gage.

5. Approved jig-produced parts used as sub-standards or patterns. These are not employed for components possessing close tolerances. In some instances, rejected Dural parts are suitably strengthened and reworked into an interchangeability setting fixture for assembly jigs, and the Dural structure is considered better than a steel sub-standard because the coefficient of expansion is the same as the work.

The British do not permit adjustable pick-up points in aircraft-component assembly jigs. Replicas of the counterpart

attachments are bedded and bolted to the jig, and after location either with mechanical or optical jig references they are finally dowelled. If displacement is discovered during periodic inspection of the jigs, the pick-ups are remachined and redowelled.

In general the British find that mechanical jig references are not as elaborate and costly as gages, particularly for the large components. And a male jig reference, when approved by M.A.P. inspectors, can be used to make and check the female jig reference, or reference for the counterpart. Whereupon another male reference can be made to the approved female, and so on until the required number of references are obtained for production purposes.

Optical Jig References

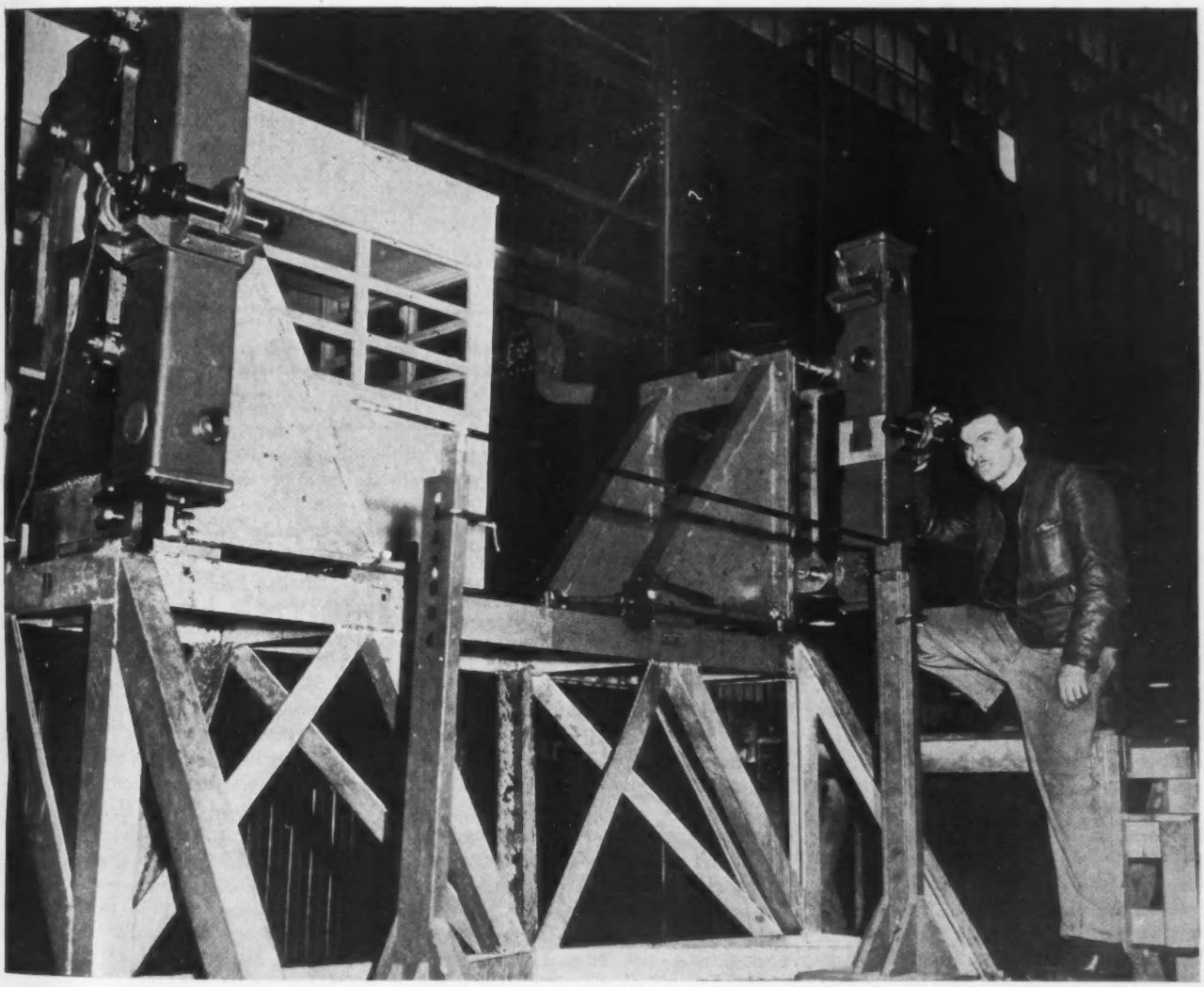
Use of optical jig references for checking a jig is not a time-consuming process. The entire operation for a centerplane jig requires about two hours, and if need be relocation of pick-ups can ordinarily be accomplished in a shift.

The ease with which optical jig references can be used, and the extreme accuracy which they permit in location of interchangeability features of large jigs, warrants further discussion. Construction details of the references follow:

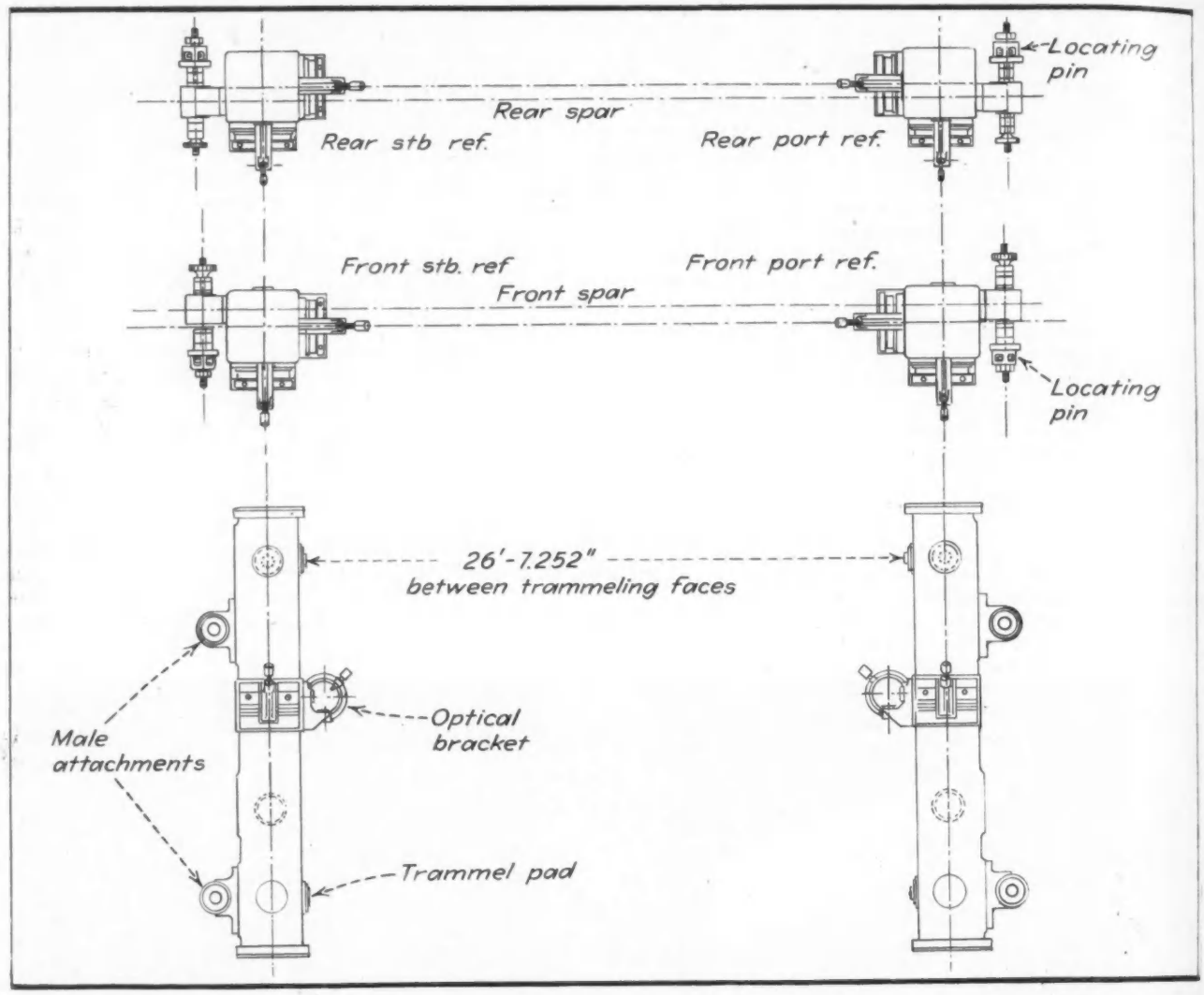
Optical jig references are of two types: (1) Box-section light-alloy castings (as in the case of the centerplane equipment) to which the V-block brackets and male-attachment brackets or pickups are assembled, or (2) a seamless steel tube upon which similar brackets are pinned. Both kinds of jig references must be light in weight, but the latter has the advantage that the brackets can incorporate compound angles (as in the case of the outerwing jig-attachment points) so that only one sight need be made between distant attachment points having an angular relationship.

The greatest of care is required in making optical jig references. V-blocks for the telescope and collimator have a limit for misalignment of 0.0005 in. in 24 in. The axis of holes in the male attachments must be perfectly parallel and in the same plane (for a centerplane reference). Taper holes are used in the male attachments. The clamping face at the small end of the bore must be perfectly at right angles in two planes to the hole axis, and in the same plane with the other attachment clamping face to within 0.0005 in. in 24 inches.

A special mounting pin is used to fasten each of the two male attachment points of the jig reference to the female attachment points built into the jig. These pins consist of a double taper cone. The long taper seats in the male attachment hole, and its protruding tip is aligned in one fork of the female attachment by means of an expansible sleeve, or three-part collet. The short taper is similarly aligned in the other fork of the female attachment. Ring nuts at both ends of the pin seat the



By means of the optical alignment telescope, the inspector is checking tilt and displacement of wing-spar pick-ups at one end of the centerplane jig. The collimator is mounted in the jig reference at left. A Johannson inside micrometer, placed on the wood V block stands, is employed to trammel the distance between the gaging pads fastened to the jig references.



A complete check-up of the wing-spar pick-ups in a centerplane jig can be made in two hours. Here is the diagrammatic arrangement of the four jig references employed, one at each corner of the jig. Cast references are used in this instance.

collets in the female attachment and a large cap nut draws the clamping face of the male attachment snugly against the female attachment.

The use of optical jig references and the reasons for their application can be explained in relation to the centerplane assembly jig. The centerplane consists principally of front and rear spars fastened across the front and rear of the center fuselage section. The spars have been predrilled on drill-referenced jigs before installation in the centerplane assembly jig. All riveting operations on the centerplane are carried out, and the structure is released so that any distortion will be relieved before final reaming of the outerwing attachment holes in the ends of the front and rear spars. It is essential that these holes after reaming must not deviate more than 0.001 in. from established centerlines. This requirement must be met, even though the holes fall at the corners of a rectangle measuring approximately 26x90 in., and the spars are approximately 30 ft. long.

To achieve this degree of accuracy, the bushings for final hand reaming of the spar-attachment holes must be referenced by the optical method. Accordingly, an optical reference is installed at each corner of the jig, being mounted on the female attachments by the special pins described. The sequence of checking the jig is as follows:

1. One reference, say that at the port side of the front spar, is selected as a datum. A telescope is mounted in the V-block so that it can be sighted upon a collimator mounted on the reference at the starboard end of the jig. Tilt and displacement measurements are made. The distance between the trammel pads is checked with Johannson inside micrometers. If the attachment points show tilt or displacement outside allowable limits, they are removed and remachined until satisfactory. No adjustment is provided in the mounting of female attachments, which are actually jig references, because it is felt that riveting vibration might disturb the settings.

When the jig is originally set up, the collimator readings must be zero. At periodic checks, say one month apart, it is permissible to have deviation within allowable tolerances.

2. If the starboard front spar reference checks satisfactorily, the collimator is moved to the starboard rear spar, and the telescope is advanced to the second reference. Tilt and displacement readings are made, the distance between references is trammeled and any necessary corrections are made.

3. When the complete round of the rectangle has been made, the procedure is reversed for a double check.

It might be thought that British interchangeability media are relatively expensive. Yet spread over the first 1,000 Lancasters built in England, the cost of the interchangeability equipment per plane amounted to approximately $250. That is considered an infinitesimal expenditure to insure prompt repair of worn or damaged aircraft by the fighting service.

Proper Design of Plastics Parts Depends on Selection of Material

W. S. LARSON
Plastics Department, General Electric Company

Types of materials available, methods of manufacturing and comparative costs are covered in this first of a series of articles on designing with plastics.

BECAUSE there are so many apparently unrelated types of material available and several unconventional methods of processing these materials it is not surprising that there should be considerable confusion with respect to selecting and specifying plastic materials. Each material has its limitations, of course, just as each processing method is not suited to all materials.

To select the proper material for a particular application requires a familiarity on the part of designers of the limitations of each material and processing method. Therefore, the data and information in this series of articles has been assembled so that these limitations will be more readily apparent. Assembly of this material, though, has its limitations because to cover the entire field of plastics in detail would be a lifetime job. So, the material presented is intended for the designer who wishes to be sufficiently familiar with plastics to be able to recognize an advantageous application and to specify the design for it. It will exclude materials for such uses as plastic coatings and adhesives, solutions for treating cloth and paper and binders for sub-plastics.

Types of Material Available

Plastic materials can be classified in several ways. One of the simplest is based on the manner in which the molecular framework is formed, and which is demonstrated by the ability of the material to withstand heat distortion. A material which polymerizes to form a rigid three dimensional molecular framework becomes infusible after molding and is known as *thermosetting*. Phenolic, urea and melamine resins are the best known of this class. If the material polymerizes into flexible, linear molecular chains, it is permanently fusible, and must be "set" in its desired shape by cooling. Such a material is *thermoplastic* and can be readily distorted or remolded under heat. Cellulose acetate, polymethyl methacrylate and polystyrene are representative.

For engineering purposes, however, a more specific and descriptive classification is necessary. Therefore, the following items should be included:

1. The name of the resin which gives the compound its moldability and coherence, such as "phenol formaldehyde," "cellulose acetate."

2. The name of the special property and/or the name of the fillers and modifying agents which distinguish this compound, such as "impact resistant," "plasticized," "wood-flour filled."

3. The name of the type of molding for which the material is to be used, such as "extrusion grade," "casting resin," "low pressure laminated." If the material is to be purchased in stock shapes such as sheets, rods or tubes, the methods of fabrication which are to be used should then be given, such as "punching," "machining," "drawing."

The specification of a plastic material has many further refinements, such as

Thermoplastic

Material	Customary Classifications	Forms Available	Typical Trade Names	Outstanding Properties
Celulose acetate	General purpose, with wide choice of flows and special grades for injection and compression molding and extrusion	Custom moldings and extrusions Stock sheets, rods, tubes, foil	Bakelite, C. A. Fibestos Herculoid Lumarith Nixonite Plastacele Tenite I	Readily molded, tough, wide range of colors and effects
	High acetyl content			Improved heat and moisture resistance
Cellulose nitrate		Extruded rods, tubes and films Stock sheets Custom moldings and blown forms from stock sheet	Amerith Celluloid Hercules C. N. Nitron Nixonoid Pyralin	Toughness, water resistance, highly inflammable, limited moldability
Cellulose acetate butyrate		Custom moldings and extrusions Stock sheets	Tenite II	Good moldability, good dimensional stability, improved moisture resistance
Ethyl cellulose	General purpose	Custom moldings and extrusions Stock sheets, rods, tubes, film, casting resin	Ethocel Hercules E. C. Lumarith E. C. Nixon E. C. Ethofoil	Good moisture resistance, toughness
	Low temperature			Flexibility and good low temperature properties
	Highly plasticized			High elasticity and flexibility
Polymethyl methacrylate	General purpose	Cast shapes, sheets, rods Custom moldings and extrusions	Lucite, Plexiglas	Excellent transparency and light "piping" ability
	High heat resistant			Improved heat and moisture resistance

(continued on next page)

Thermoplastic (continued)

Material	Customary Classifications	Forms Available	Typical Trade Names	Outstanding Properties
Polystyrene	General purpose	Custom moldings and extrusions	Bakelite Loalin Lustron Styron	Excellent electrical properties and moisture resistance, chemical resistance
	Modified resin		Styramic	Improved heat resistance and non-flammability
Vinylidene chloride		Custom moldings and extrusions Stock rods, tubes, films	Saran	High tensile strength, water and chemical resistance, crystalline structure, good moldability for heavy sections
Vinyl chloride		Custom extrusions and formed sheet Stock sheet	Koron Koroseal Vinylite Q	Flexibility plus flame, oil and corrosion resistance
Vinyl chloride-acetate copolymer	Rigid or non-plasticized	Custom moldings and extrusions Stock sheets, rods, tubes	Vinylite V	Chemical resistance, dimensional stability
	Elastic or plasticized			Extremely flexible
Nylon		Custom moldings and extrusions Filaments	Nylon	Improved heat resistance, high tensile strength, limited moldability
Polyvinyl alcohol		Custom moldings, sheets, films	PVA Resistoflex	Chemical resistance plus flexibility
Mycalex		Custom moldings Stock plates, rods	GE Mycalex	Good electrical properties, high heat resistance
Shellac		Custom moldings, laminated tubes	Complac Electrose Harvite Lacanite	Good electrical properties, good moisture resistance, scratch resistance

Thermosetting

Material	Customary Classifications	Forms Available	Typical Trade Names	Outstanding Properties
Phenolics Phenol-formaldehyde Cresol-formaldehyde Phenol-furfural and related resins	Unfilled compound	Molded Shapes	Bakelite Durez Durite Heresite Indur Insurok Makalot Resinox Textolite	Transparency plus heat resistance
	General purpose Woodflour filler Cotton flock filler			Good moldability and finish, low cost
	Miscellaneous Graphite Diatomaceous earth Metallic powder Abrasives			Fillers selected for special properties such as hardness, lubricating surface, electrical conductivity, abrasiveness
	Heat resistant Asbestos			Best heat resistance and dimensional stability of phenolics
	Improved electrical Mica			Improved dielectric strength and power factor
	High impact Rag fiber Cut fabric Cut cord			Increased impact strength, limited moldability
	Resin board		Bakelite,	
	Sisal fiber		Co-Ro-Lite	
	Creped paper		Resin-X-Crepe	
	Pulp preform		Kysite	
	High pressure molded Laminated paper, cloth	Molded shapes		High flexural and impact strength with thin cross sections, limited moldability
	Low pressure molded Laminated paper, cloth, wood veneer			High mechanical strengths, unlimited size and difficult shapes
	Paper base X, XX, XXX, P, XXP, XXXP	Laminated sheets, rods, tubes	Aqualite Celeron Dilecto Formica Insurok Lamicoid Micarta Panelyte Phenolite Spauldite Synthane Taylor Textolite	Good mechanical and electri al properties, can be punched
	Heavy weave fabric C, CE			Best impact strength of laminated
	Light weave fabric L, LE			Good impact strength plus good electrical properties
	Asbestos A, AA			Flame resistance and dimensional stability
	Fiberglas cloth			Good mechanical plus heat resistance
	Wood veneer			High strength-weight ratio, decorative uses
	Casting resin Unfilled General purpose	Custom castings, stock sheets, rods and tubes	Bakelite, C. R. Baker, C. R. Catalin Gemstone Haveg Marblette Opalon Textolite	Beautiful colors, excellent machinability, low mold costs
	Technical resins			Additional chemical resistance
	Filled	Custom castings		High compressive strength and rigidity, large castings

Thermosetting (continued)

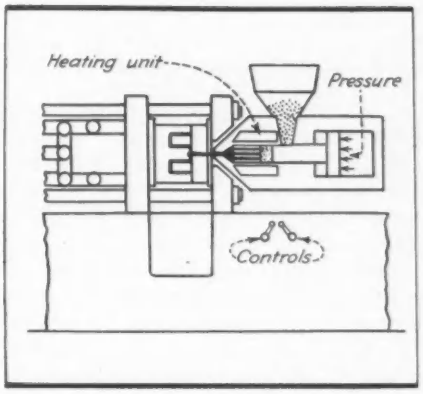
Material	Customary Classifications	Forms Available	Typical Trade Names	Outstanding Properties
Urea-formaldehyde	General purpose Alpha-cellulose filled	Molded shapes	Bakelite Urea Beetle Plaskon Uformite	Available in white and light colors, good electrical properties
	Paper and cloth base materials similar to phenolic laminated	Laminated sheets, rods and tubes		Translucence, improved electrical properties, abrasion resistance
Melamine-formaldehyde	General purpose Alpha-cellulose filler	Molded shapes	Catalin Melamine Melmac, Plaskon Melamine	High arc resistance and dielectric strength Chemical inertness Available in white and colors Good abrasion resistance
	Impact material Fabric filled			
	Heat resistant Mineral filled			
	Industrial and decorative laminates with paper and cloth filler	Laminated sheet, rods, tubes		
Casein		Custom extrusions; stock sheets, rods, tubes	Ameroid Galorn	Good color choice Poor moisture resistance
Allyl resins		Custom castings; stock sheets, rods, tubes; laminated shapes, sheets, rods	CR-39	Clear transparent High heat distortion Hardness and abrasion resistance
Polymerization resins		Impregnating resins for laminating	Bakelite Laminac	Thermosetting Good electrical properties
Cold molded	Refractory, or inorganic	Custom moldings	Aico Cetec Ebrok Coltstone Alphide Garit Okon Thermoplax	Very high heat resistance Hard Poor finish
	Non-refractory, or organic			High heat resistance Low cost material Poor finish

the fine distinctions in the formulations to accommodate difficult molding conditions and special appearance. However, application of these formulations is the responsibility of experienced plastics engineers or molders. The accompanying tables list the most frequently used plastics in the manner outlined above.

Methods of Manufacturing

Plastic materials are processed by a wide variety of means. The size and shape of the desired product is the chief governing factor which decides whether or not the part should be molded, fabricated, cast, extruded or drawn. Other criteria are the material to be used, the forms in which it is available, and the property and design limitations which it imposes. Inversely, in order to make a correct selection of material, it is essential that the designer be familiar with these fabricating processes.

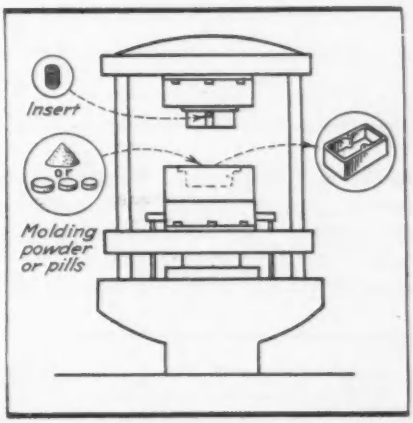
Injection Molding is used for thermoplastic materials, but modifications designed to adapt these presses to thermosetting material are being developed. Material fed into the cylinder is advanced into the heating zone with each injection. Material is heated to 300-400 deg. F. and is injected at pressures of 20,000 to 30,000 lb. per sq. in. Mold costs per cavity are approximately equal to compression molds, but usually fewer cavities are required. An average molding cycle is 45 sec. and 6,000 parts per week is a typical production per cavity.



The weight of charge is limited to 12 oz. for most machines. Maximum projected part area of approximately 300 sq. in. is the limit.

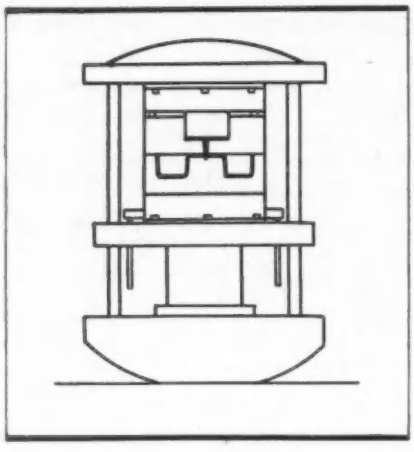
Jet Molding is a modification of injection molding to permit molding of thermosetting materials or unstable thermoplastic materials in the regular injection-molding machine. It offers the advantages of transfer molding plus rapid production per cavity. Mold costs per cavity are approximately equal to compression molding, but fewer cavities may be required. At present, a weight of charge of approximately 16 oz. and a projected area of 125 sq. in. are the limits.

Compression Molding. Granular or preformed molding compound or forms are placed into the hardened steel molding cavity. The mold is hot, 280-350 deg. F. and is closed under pressures of 2 to 4 tons per sq. in. of projected part area. The plastic part is formed and allowed to become rigid by heat polymerization for thermosetting compounds or by cooling for thermoplastic compounds. An average production cycle is 5 minutes and 1,000 parts per week in typical from a single-cavity mold. Because of



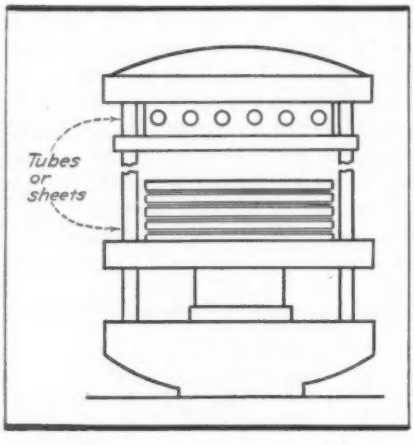
the pressure required, compression-molded parts are restricted to projected areas of approximately 600 sq. in. and weights of 20 lb.

Transfer Molding is a modification of compression molding in which the material is first placed in a pot above the mold, and is then forced by a plunger into the closed mold cavity. The primary advantage is the even dis-

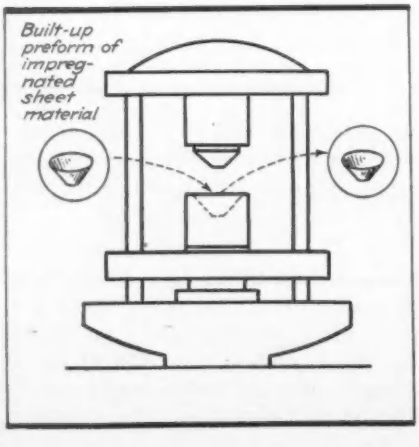


tribution of pressure exerted on delicate mold parts or inserts which would be crushed by compression molding.

Laminated Plastics. Sheets, rods and tubes of impregnated cloth and paper are pressed as stock items by commercial laminators. The filler materials are pressed between flat platens or split cylinders. Available stock sizes are limited by press capacity.

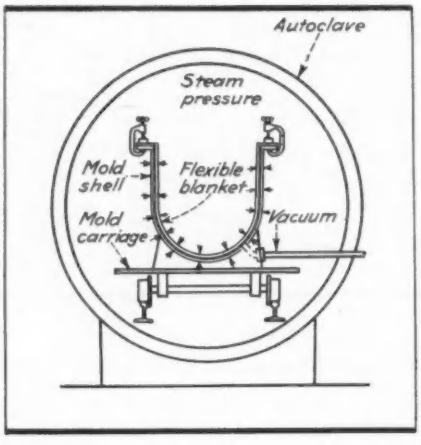


Molded Laminated, High Pressure. Simple shapes with uniform cross-sections can be molded to shape out of sheets of impregnated cloth or paper in the manner shown here. These

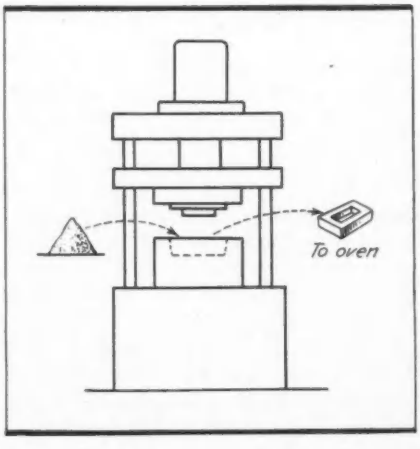


parts have high flexural and impact strength for their relatively thin cross-section. Molds are generally simpler and less expensive than compression molds.

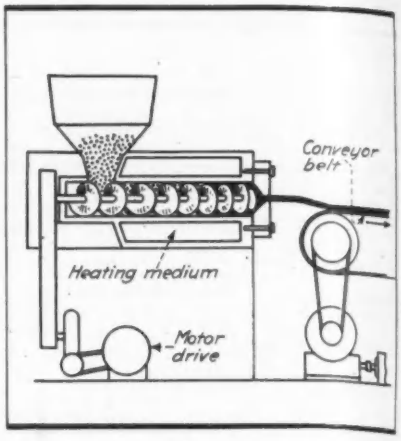
Molded Laminated, Low Pressure. By sandwiching impregnated cloth, paper or wood between a mold form and a rubber blanket and applying 160 to 340 deg. F. heat and 5 to 100 lb. per sq. in. pressure, plastic parts of unlimited size can be made. Forms are made of wood, metal, plaster of paris or similar compositions.



Cold-Molded parts are merely shaped to form in a cold or warm steel mold, and cured outside of the mold in an oven. Molds are made of steel but many less cavities are required because the cycle is rapid and the cure is completed outside of the mold. Pressures of 1 to 2 tons per sq. in. are required.

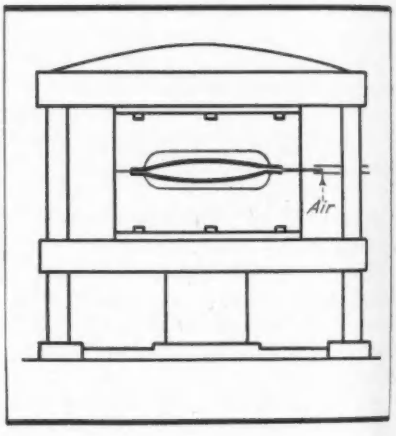


Continuous Extrusion is accomplished by forcing thermoplastic compound through a heating chamber and out of an orifice of the desired shape. Thus, cross-sections up to 3 sq. in. are commonly extruded in any length. Dies are made of steel and are relatively

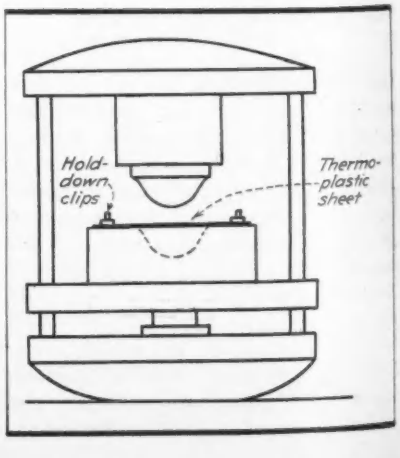


simple and low in cost. Many stock shapes of rods, tubes and trim are available.

Blowing. Hollow and thin sections can be made from thermoplastic sheet stock by forcing the soft material against the die surface with compressed air. Dies are generally simple in shape and low in cost compared to compression-molded parts. Cellulose nitrate sheet 0.0015 in. thick is commonly used for this operation; thicker sheets can also be formed.



Drawing and Forming. Thermoplastic sheet material and, to a lesser degree, thermosetting laminated mate-



rial can be drawn into cavities or over plungers. The sheet material is heated in ovens and is formed to its desired shape while soft. Little or no pressure is required.

Casting. Liquid casting resins of phenolic, methacrylate or styrene can be cast into simple shapes by pouring into lead, rubber, glass or composition molds and baking. Lead molds for commercial production are made by dipping a steel mandrel into a lead bath. Molds can range from simple tapered shells to more complicated split or cored molds.

Fabrication. Plastics of every type are available for machining and assembling of small quantities, models or special parts. Especially adaptable to this type of work are the cloth-filled laminated materials and sheets, rods and tubes of cellulose acetate, cast phenolic and cast methacrylate. In general, this is a special-case procedure and should be considered on that basis.

Costs

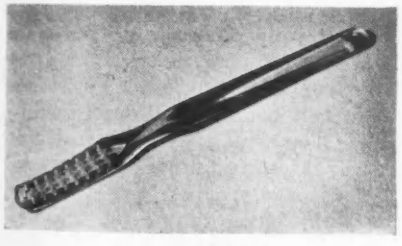
Costs of typical plastic parts will necessarily vary in different companies and localities but, in general, the figures given below are an approximation of what plastic parts cost and what factors determine that cost. If the part under consideration has a unique size and shape and is to be custom molded the first cost will be the purchase of the necessary molds, dies and fixtures.

The cost of a particular molded part, disregarding mold amortization, is a function of the material and the direct labor costs which go into its manufacture. It is misleading to list material costs in dollars per pound without considering either the parts produced per pound or the cost of labor which that particular type of material and manufacturing process involve. The parts illustrated are typical of various materials and processes.

[Editor's Note—The next article in this series will begin a discussion of various physical properties of plastic materials from the standpoint of their design limitations.]

Approximate Costs for Various Types of Molds

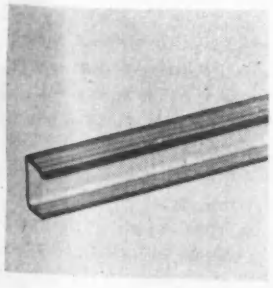
Type of Mold	Typical Part	Mold Cost
Hardened steel molds for high-pressure molding (compression, transfer, injection, jet)	Small part (3-in. dia. or equivalent) Simple draw	$300 to $500 for single-cavity mold; $200 to $400 for each additional cavity; lower cost on additional cavities if hobbed
	Complicated undercut parts or larger mold	Up to $400
Steel mandrels for lead molds for casting	Rods and Tubes	Simple draw molds $100 to $400 Cored molds $300 to $800 Split molds $250 to $550
Extrusion dies	Trim strip 1 in. wide	$100
		$50 to $200 for simple solid cross-sections
Wood, plaster or metal forms for low-pressure laminated molding	12-in. radius hemisphere	$400
		Wide range, $200 to $5,000 depending on size, shape and material



Lots of 250,000
1.5 cents each
Cellulose acetate
Injection molded
16 cavities

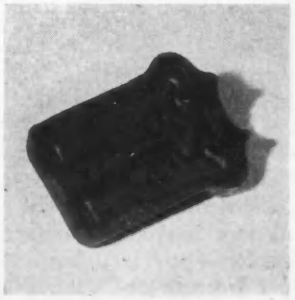
Approximate Costs of Phenol-Formaldehyde Laminated Products in Economical Lots

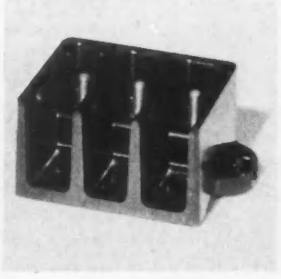
Material	Size	Price
Paper base	36 x 36-in. sheet	$0.48 lb.
Canvas base	36 x 36-in. sheet	0.66 lb.
Paper base	1-in. O. D. rod, 35 in. long	0.86 ft.
Canvas base	1-in. O. D. rod, 35 in. long	1.25 ft.
Paper base	1-in. O. D. tube, ⅛-in. wall	0.28 ft.
Canvas base	1-in. O. D. tube, ⅛-in. wall	0.52 ft.



Lots of 100,000 ft.
3.5 cents per ft.
Polystyrene
Extruded
Single die

Lots of 25,000
2 cents each
Bituminous, non-refractory
Cold molded
Single-cavity mold





Lots of 3,500
18 cents each
Phenolic, rag-fiber filler
Compression molded
Single-cavity mold

Lots of 30,000
7 cents each
Phenolic, wood-flour filler
Compression molded
4-cavity mold

WARTIME DESIGN NEWS

Reconversion Thinking

NO FLAT PROHIBITION will be laid on industrial and engineering enterprise which desires to shift into a new line when the war program permits it to revert to its own pursuits. Knowledge that many firms which, by reason of their war experience or otherwise, plan either to drop their pre-war product for another, or expand by adding others has worried war production officialdom for months. The issue, whether government authority actually has or feels that it has an obligation to attempt to preserve the pre-war pattern of industry as it moves into the transition period, has been brought sharply into focus by the increasing surplus of certain materials over war requirements. Both the Truman committee of the Senate and Donald Nelson, WPB chairman, have faced the problem squarely and concluded that it would be unwise and futile to attempt to freeze industry into its pre-war pattern. It is obvious, of course, that any fetters which the government might seek to impose eventually would be shattered by the force of competition. The Truman committee declares that, with respect to such increased civilian production as becomes possible, a manufacturer should be allowed to make anything he desires. Nelson agrees in principle, asserting that "if, with the return of peace, we were to start out with the policy of planning our peacetime economy in detail, as we would have to do in order to prevent new competition, we would do irreparable injury to the free enterprise system."

Until the now critical components and materials are readily available, Nelson contends, restrictions should be placed on "new" companies.

"Certainly, so long as wartime controls are retained," writes Nelson to Sen. Francis Maloney, Connecticut Democrat, "materials and components should not be allocated to these 'new' firms until firms already established in the affected industries, and which are in a position to resume production of their former products, have received their just allocations."

Though this seem contradictory, it simply means that firms already established in a given industry will be taken care of first so long as there are not enough materials for everybody in that industry who wants them. To get into peacetime work, of course, the established firm will have to be free of war work and so located as to be able to resume such production without affecting the war labor supply of the region. Consequently, as long as materials and labor are tight, newcomers will not have a clear field but the door is by no means locked to them, and no restraint whatever will be put upon them when the need for wartime controls disappears.

Civilians Win Out

WPB's reconversion thinking, in playing down the protection of industries against newcomers, plays up the production of civilian goods wherever possible and the prevention of local unemployment. This is not entirely in line with the wishes of the military, who think that more fat must come off the civilian living scale and who argue that continued restriction of civilian production, even where it might otherwise be possible, would drive unemployed labor into labor shortage areas where it could be rushed into the remaining critical programs. Labor's failure to move from those few areas in which unemployment has thus far become apparent is probably the principal reason why the military's wishes no longer completely govern reconversion thinking.

WPB apparently has given up its idea of starting all companies in a given industry from scratch when civilian production resumes. This may not be to the liking of those companies whose ability to produce efficiently for the war has tied them up with long-term military contracts while their competitors in the civilian market whose war production can be dispensed with are free to resume civilian production and promotion, but the pressure for increased civilian production and labor's failure to migrate to tight manpower areas has left no reason for keeping idle facilities under wraps once materials, components and labor are available.

Production quotas, based on pre-war division of the market, probably will be used only when they do not interfere with more important factors—production of civilian goods and prevention of wholesale layoffs. The feeling is that these quotas put reconversion into a straightjacket at the time when flexibility is most needed. Under the electric-iron program, guinea pig for reconversion plans affecting consumer durable goods, manufacturers were allowed such quotas, and those who were not free to make their own irons were allowed to have their quota made for them, to carry their own trademarks. The use of such trademarks on goods made for a war-bound manufacturer will probably be a part of future reconversion programs, but the quota system based on pre-war output appears to be out.

In its place, WPB is thinking of shuffling schedules of civilian production so as to enable plants where severe war cutbacks have occurred to maintain operations at maximum production and employment levels.

Whatever the final reconversion pattern proves to be, and there is lots of argument about its broad outlines and its details, it is final that reconversion must await not only the second front but, more important, the success of the invasion. Military thinking has controlled on this point, and almost certainly will not be challenged successfully. The strategists point out that getting ashore in Europe—and in force—will be the toughest single military and naval operation in history, and as such could be unsuccessful. Thus, they do not want to face the prospect of having to reconvert all over again those plants which had gone back to peacetime production from war work.

"Bazooka" Magic

THE ARMY has made no announcement of it, but censorship has lifted at last on the rocket projectile fired from the U. S. "bazooka" with such devastating effect.

Credit for revealing the "secret" of the "bazooka" projectile's charge, which for a year now has been a poorly kept secret, goes to the *Infantry Journal*, which in a recent issue attributed the projectile's fantastic effect to the use of the long-known Munroe principle.

The charge, commonly known among military men as the "shaped" or "hollow" charge, is hollowed out to resemble the inside of a tapered cylinder. Its de-

structiveness is attributed by *Infantry Journal* author Leonard Engel to the "mutual compression of the explosive shock waves inside the cylinder; the hole blasted always has the same diameter as the open cylinder of the explosive."

The Munroe principle was discovered about the turn of the century by Charles E. Munroe, a Columbia University professor who found that a charge which did no damage to a steel safe when used normally blasted a hole completely through the safe wall when shaped. The hollow charge, Engel says, proved to be around ten times as effective as solid charges. The discovery, patented and thus widely available, languished, for military purposes, until this war, when the Germans as well as ourselves, and probably all the other belligerents, began to adapt it to weapons.

The charge propelling the "bazooka" projectile is relatively small and is designed to be completely consumed in the "bazooka" tube, since a charge which burned after the projectile left the tube would wreak havoc on the gunner. Rocket projectiles which are fired from a distance and with only general aim have vastly greater range and velocity than the "bazooka" shell.

Readers of PRODUCT ENGINEERING who are interested in rocketry and a general history of the art will find Engel's article (*Infantry Journal*, Jan., 1944, Infantry Journal, Inc., 1115 17th St., N.W., Washington, D. C., 35 cents) of considerable interest.

Airworthiness Committee

W. E. BEALL, vice-president of engineering of the Boeing Aircraft Company, is chairman of the new Airworthiness Committee of the Aeronautical Chamber of Commerce which will hold its first annual meeting this month at St. Louis.

Operating under the chamber's Airplane Technical Committee, the new group will coordinate airworthiness problems with company technical specialists and engineering management; will initiate study or experiment relative to proposed new requirements or revision of existing requirements, taking such action on its own motion or at government request; will provide federal agencies with a single industry source on airworthiness problems; will represent the aircraft industry before the government in the matter of any uniform international requirements; and will promote standardization of Army, Navy and civil design criteria, preparing and submitting to such federal agencies the industry's recommendations.

Forty-one companies are represented on the committee, the membership of which will be divided into eastern and

Circular Side Armor Sheds Gunfire

U. S. Army Signal Corps Photo

Jap light tank captured on Kiska last summer was partially disabled. The track appears to have steel rather than rubber treads. Circular side armor is designed to shed gunfire. Gage of the turret covers and the cover of the entrance port just in front of the turret indicate that this vehicle would be vulnerable to .50 cal. machine-gun fire at moderate ranges, and certainly to 37 mm. anti-tank gun fire when armor-piercing projectiles are utilized.

Jap Naval Rifle Is Well Armored

U. S. Army Signal Corps Photo

Camouflaged shore defense rifle was abandoned by the Japs on Little Kiska when they evacuated their last Aleutian stronghold last summer. This is a 6-in. naval rifle, apparently of Jap design and manufacture rather than a captured piece. It appears to be well armored, particularly against air attack.

Mustang Fighter Also Carries Bombs

Army Air Forces Photo

North American Aviation's new P-51 Mustang fighter has been guarding the Fortresses and Liberators over Berlin and other targets deep in Germany. The P-51 can also be used as a fighter-bomber, carrying a 1,000-lb. bomb load. Service ceiling of this model is well over 30,000 ft., where its speed is above 400 m.p.h. Despite increased weight, this craft has longer range than its predecessors, and possibly has the greatest operational range of any U. S. fighter.

western sections, with the Rocky Mountains the dividing line. Subcommittees to work on specific assigned design problems will do much of the work of the committee, the policy of which will be in the hands of a five-member steering committee. Herbert Rawdon, assistant chief engineer of Beech Aircraft Corporation, and Beall are members of the steering committee, with three other members to be selected.

Cold Research

THE ORDNANCE DEPARTMENT has established the world's shortest firing range —22 ft. long—for research and testing on the new aerial cannon with which the new bombers are being armed.

Located at Eglin Field, Fla., the range will provide stratosphere temperatures, down to —70 deg. F., in which the effects of extreme cold and lack of oxygen on detonation and projectile speed can be studied. Bombers which climb rapidly from sea level to the stratosphere undergo a temperature drop of 140 deg. The resulting contraction of metal gun barrels and actions must be known, as must the ballistic effects of the extremely thin air through which projectiles will pass. Effects of low moisture content of the air on the actions and of the concussion of big charges on the entire gun can now be studied at close range.

The range consists of two steel cylinders and a concrete sand trap. Men equipped with oxygen masks fire the cannon from the main stratosphere chamber in which temperature is reduced from 70 deg. F. to —70 deg. F. in 12 min. Air pressure is reduced to 2.2 lb. per sq. in., providing a partial vacuum. Gun muzzles project into the concussion chamber, in which temperatures of —67 deg. F. will be maintained.

Surplus Stocks for Sale

SURPLUS GOVERNMENT STOCKS, which are being offered for sale constantly by the Treasury Department's Procurement Division and other federal agencies, contain items otherwise obtainable only with the greatest difficulty. The Army Air Forces Redistribution and Salvage Section in particular has an extensive catalog with items ranging from office supplies to machine tools. Of specific interest to readers of PRODUCT ENGINEERING are such items in the Air Forces catalogue as raw and fabricated materials, standard parts, motors, hardware, fabrics and precision tools. Contact Army Air Forces, Materiel Command, Midcentral Procurement District, 111 W. Jackson Blvd., Chicago 4, Ill., Attention —Redistribution and Salvage Section, for information on available stocks.

Armored Car Revealed

ARMY ORDNANCE has released fragmentary details on its M8 armored car developed by the department and manufactured by the Ford Motor Company to put U. S. desert fighters on a par with those of the British and German armies.

The vehicle, which combines the speed and maneuverability of an automobile with the firepower and armor of a light tank, is a six-wheeled combat car armed with a 37-mm. cannon and a .30-cal. machine gun mounted on a turrent which can be traversed 360 deg. manually.

The M8 differs from earlier armored U. S. reconnaissance vehicles, such as the half-track, in that it has a fabricated armored hull, whereas other earlier reconnaissance vehicles had armor-plated bodies mounted upon truck chassis. The M8 offers only a low silhouette and gives a turtle-backed appearance.

The M8 carries a crew of four. Its two drivers have protected vision through steel shutters. Gunners see through periscopes which have been renamed "protectoscopes." Despite its eight tons, the M8 is capable of high speed over most terrain and can climb grades well.

A Powerful Weapon for Small Companies

LOOKING into the future, smaller manufacturers are giving a great deal of thought to their position in the post-war competitive markets. It is impossible for them to simulate the large companies with heavily staffed engineering departments and complete laboratories. The great number of new materials and manufacturing processes has further complicated the competitive outlook for the smaller companies. They cannot investigate thoroughly the adaptability of these new developments to their products.

The outlook, however, for the smaller manufacturers is by no means as dismal as it might appear at first glance. Every small organization has an inherent advantage over a large one in that closer cooperation is attainable, decisions can be made more rapidly and actions are taken quickly and directly. One-man committees are the rule, rather than heavily manned committees that are cumbersome and slow moving.

A striking example of the economies that can be effected by direct action in the small shop is found in design simplification. Needless refinements specified on drawings represent one of the biggest sources of wasted time and money in production. Tolerances are often unnecessarily small, surface finishes that are costly to produce are called for where a lesser degree of finish would be perfectly satisfactory. Sometimes the arrangement of parts in an assembly is such that toolroom accuracy is required whereas a simple revision would permit commercial tolerances obtainable by ordinary machining. Numerous other similar conditions can be found.

In a large organization it is usually difficult to expose and rectify "design luxuries." The path from the man at the machine or assembly bench to the desk of the engineer is usually a long and devious one. Design changes require many checks and approvals. Too often the production man takes a "What's the use?" attitude when he contemplates suggesting a possible design simplification. At best, in the usual course of events, it takes a long time for the change to become effective.

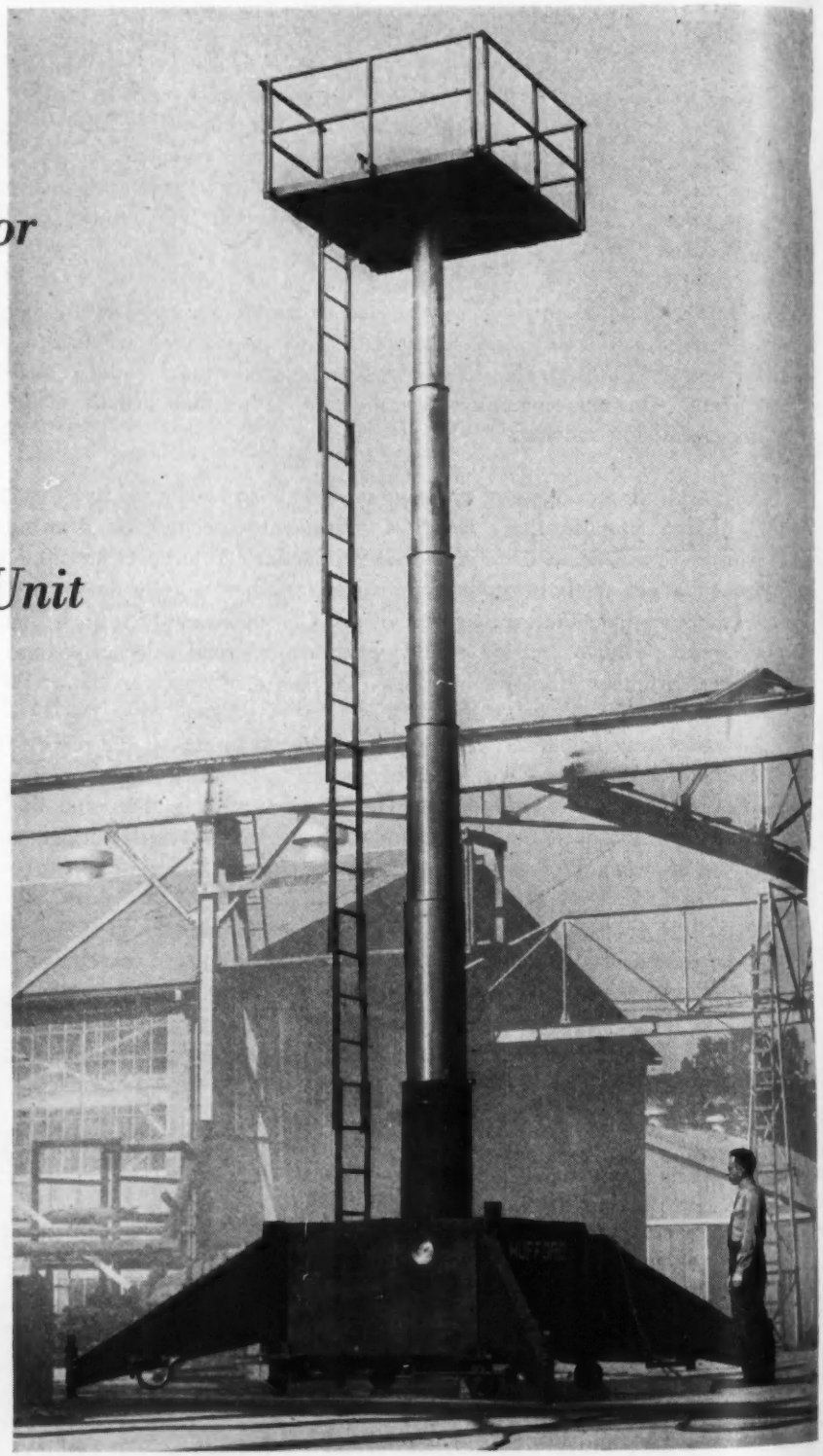
Close cooperation between the chief inspector and the chief engineer permits quick action in small- and medium-sized plants to achieve maximum production economies. The alert chief inspector checking closely on scrap percentages, operation bottlenecks and assembly difficulties, is usually the first to spot needless accuracies and non-commercial assemblies. It is a simple matter for the chief inspector to go to the chief engineer and straighten out such difficulties immediately. Rarely is further approval necessary.

The effectiveness of close cooperation and direct action is the small organization's most powerful weapon and one that should be used consistently.

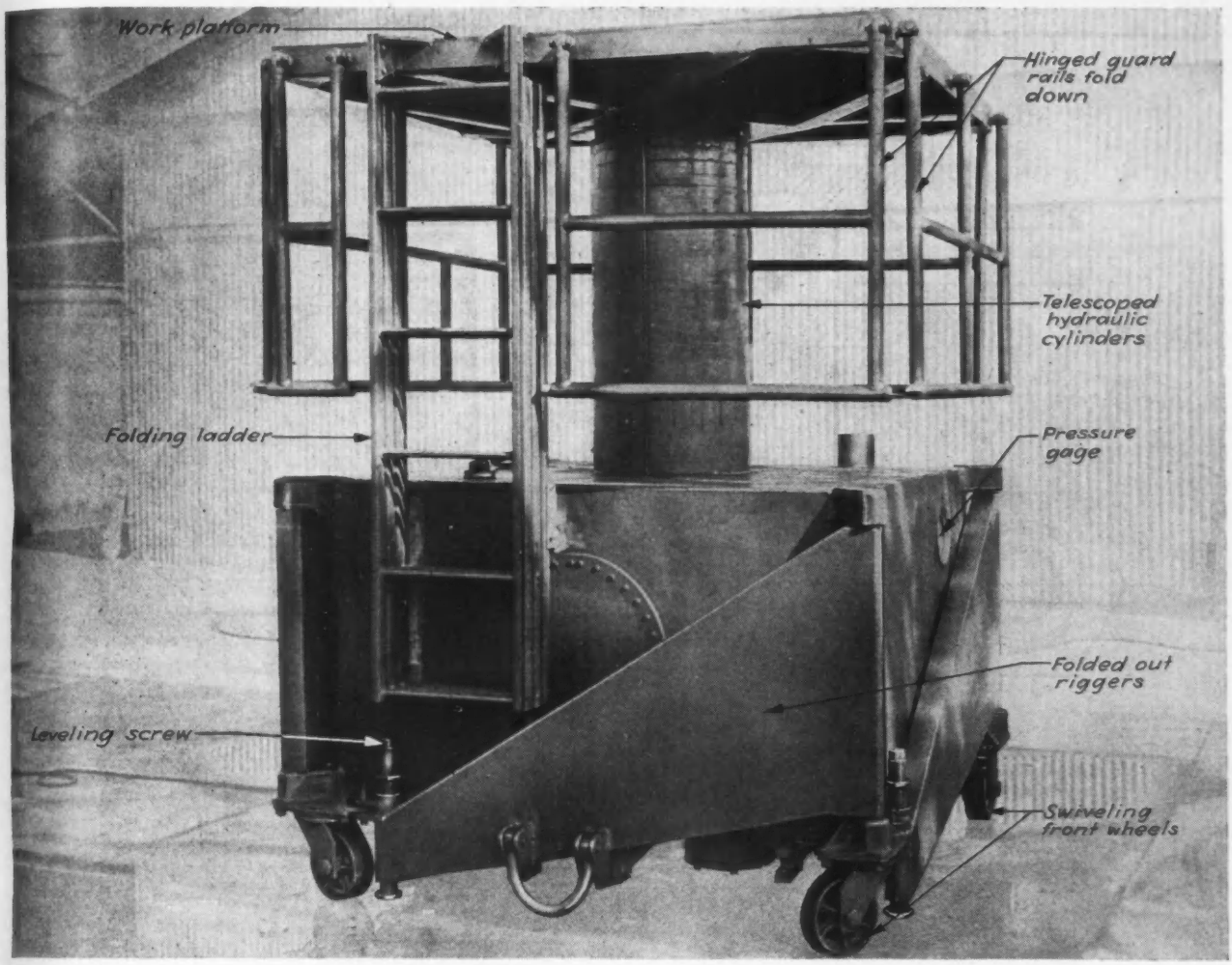
G. F. Nordenholt.

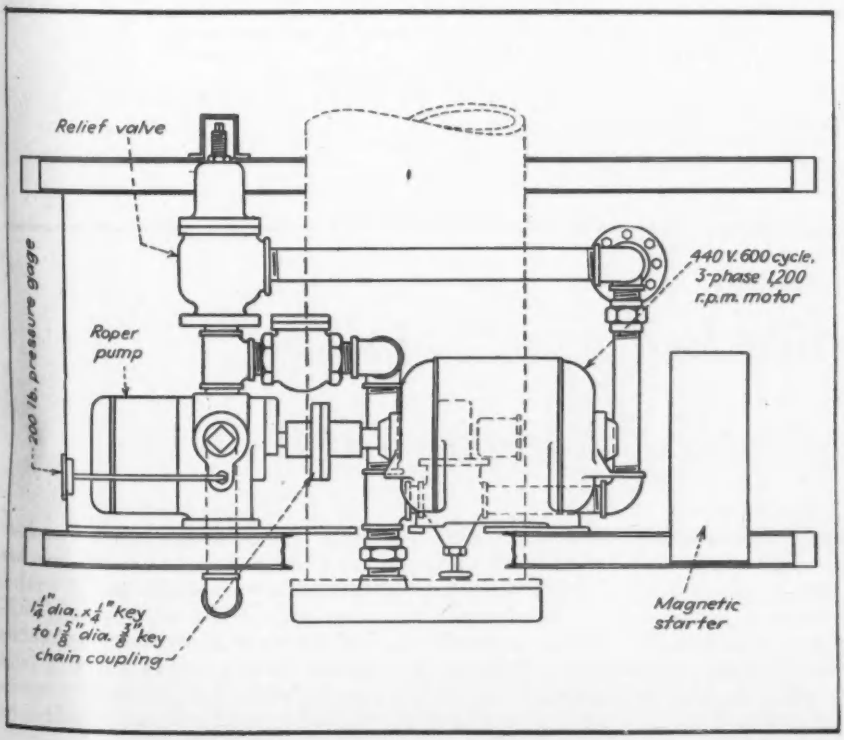
WARTIME DESIGNS

Hydraulic Elevator Telescopes Into Portable Unit

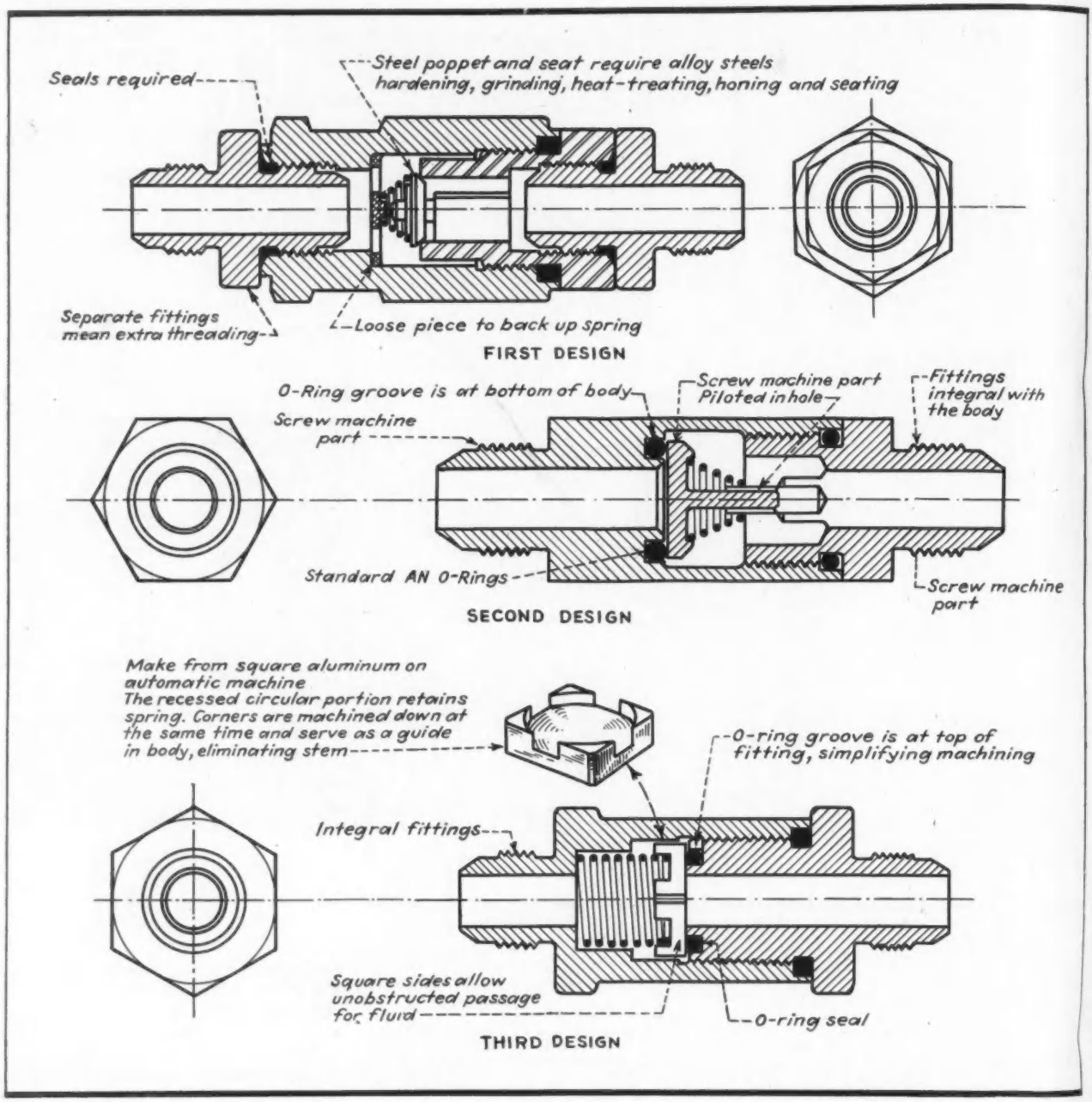


OBJECTIVE of Hufford Machine Works engineers in this new elevator design was to produce a unit for both indoor and outdoor use, completely portable, easy to set up and ready for operation by plugging-in to a light circuit. Final design is a built-up welded structure, fitted with outriggers for stability, and featuring telescoping hydraulic cylinders and folding guard rails which reduce over-all clearance to 6 by 8 ft. for towing. Model shown can lift 3,000 lb. to a maximum height of 30 ft., at a rate of 20 ft. per min. Work platform is 6 by 6 ft. in area. Power for operation of the elevator is obtained by plug-in to any convenient electrical outlet. Unit is light enough for towing by plant tow-cars. Telescoping ladder extends with the platform.




Relief valve
200 lb. pressure gage
Roper pump
440 V. 600 cycle, 3-phase 1,200 r.p.m. motor
1¼" dia. x ¼" key to 1⅝" dia. ⅜" key chain coupling
Magnetic starter

Telescoped unit ready for towing. Base, outriggers and platform are welded-up steel sheets, guard rail is welded tubing. Hinged brackets which support outriggers are welded to corners of base. Compactness is obtained by housing oil tank, pump, motor and valves in machine base. All four outriggers must be in extended position before elevator will operate. Outriggers are fitted with leveling screws to lift the unit off wheels during operation. The two front wheels are free swiveling. Rolling friction is reduced through use of Timken tapered roller bearings in all four wheels. Hydraulic cylinders are designed to take off-center loading. An additional safety feature is provided by use of a by-pass valve in the hydraulic circuit which shunts hydraulic fluid through return lines back to tank when elevator is loaded above its rated capacity. Elevator operation is controlled by three-button switch mounted on the working platform.


Seals required
Steel poppet and seat require alloy steels hardening, grinding, heat-treating, honing and seating
Separate fittings mean extra threading
Loose piece to back up spring
FIRST DESIGN
O-Ring groove is at bottom of body
Screw machine part
Screw machine part Piloted in hole
Fittings integral with the body
Standard AN O-Rings
Screw machine part
SECOND DESIGN
Make from square aluminum on automatic machine
The recessed circular portion retains spring. Corners are machined down at the same time and serve as a guide in body, eliminating stem
O-ring groove is at top of fitting, simplifying machining
Integral fittings
Square sides allow unobstructed passage for fluid
O-ring seal
THIRD DESIGN

Progressive Redesign Simplifies Manufacture, Reduces Cost

THOROUGH STUDY of part function and available manufacturing facilities led Electrol, Inc., engineers to develop a simplified check valve. The first design consisted of 11 parts, including separate fittings, and required extensive machining operations. The second development reduced to six the number of separate components and had no steel parts, but time-consuming machining operations were required to form the groove for the seal seat and piloted valve. This design used O-ring type seals. Newest design reduces machine set-ups to a minimum, has a simple valve machined from bar stock, and seal grooves located for easy machining. This valve, developed under the supervision of Ben Ashton, chief engineer, is especially applicable for very low pressures since the slight initial squeeze on the O-ring permits use of a light spring. Progressive design simplification improved valve efficiency, reduced shop time, and lowered unit cost considerably.

Redesigned Bearing Separators Save Weight, Critical Materials, Manhours

WARTIME DEMANDS for weight reduction, saving of critical metals and manhours have led engineers to make constant, critical study of conventional designs in relation to available materials and alternate fabricating methods. An outstanding example of this is found in the important savings made in gun mount separators through redesign by the Bantam Bearings Division of the Torrington Company, working in cooperation with the Navy Department. Stamped steel replaced cast bronze in three types of gun mount separators. As a result, many pounds of critical metal have been saved, weight considerably reduced, and production manhours decreased. Savings in cost are a natural reflection of combined savings in weight, bronze, manhours and transportation. Instead of each manufacturer producing his own individual separators of bronze, it is now possible for a stamping plant to turn out in a short time all the necessary steel separators for all the makers of these gun mount bearings. The stamping source can now ship

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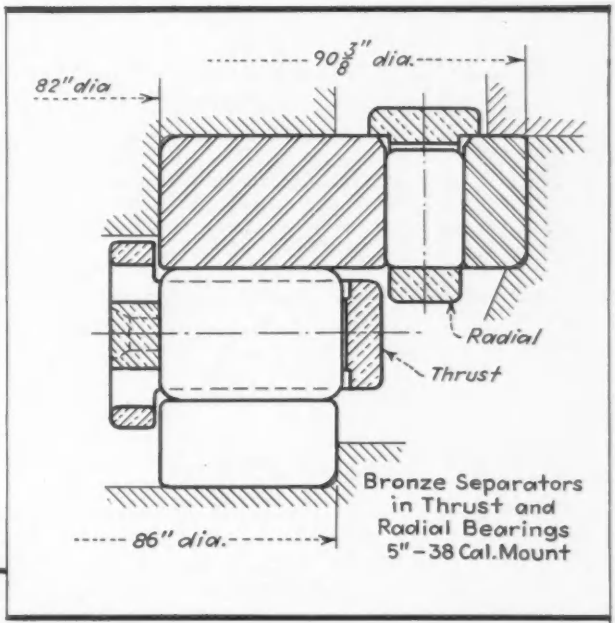
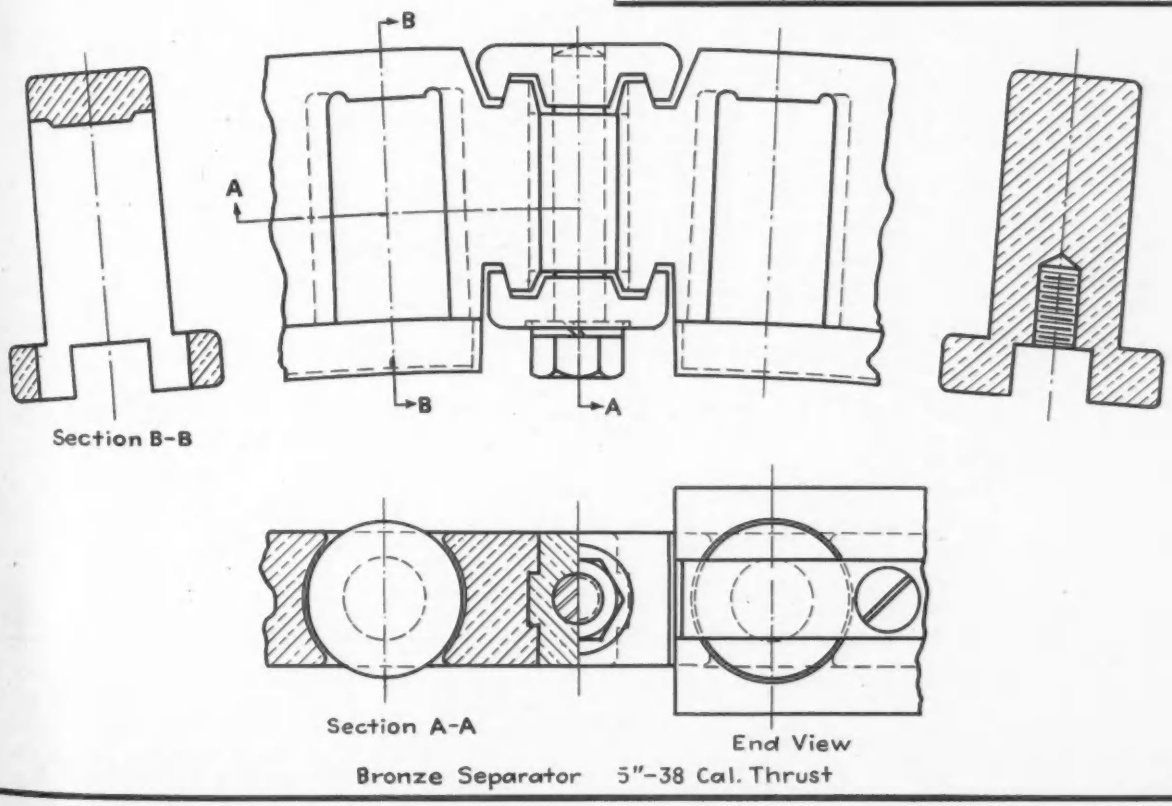




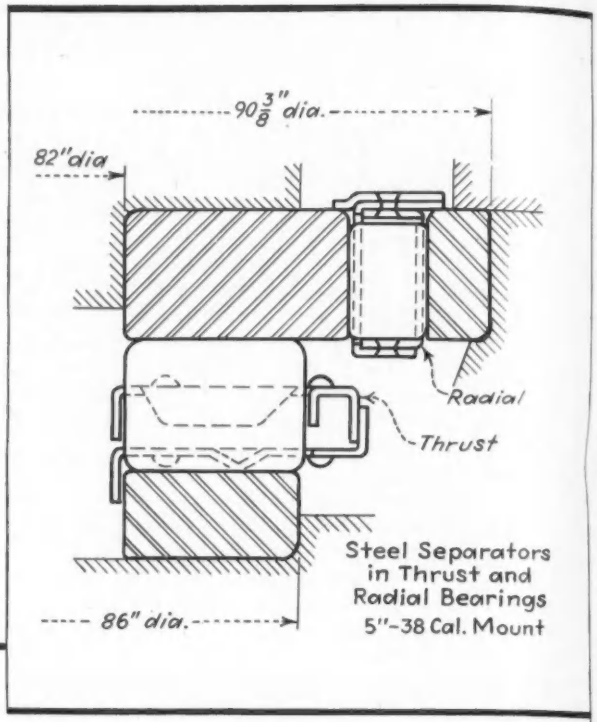
Original assembly of 5 in.-38 caliber single gun mount thrust and radial bearings has cast bronze separators. Thrust bearing sections are assembled by clamps. Each roller pocket fully incloses the roller, and cage weight is carried on the rollers. This is done to facilitate the handling of the 87 in. diameter assembly. Weight of the eight sections as cast is 224 lb. The eight sections finished, plus eight clamps weigh 176 lb. Rough castings require much machining.

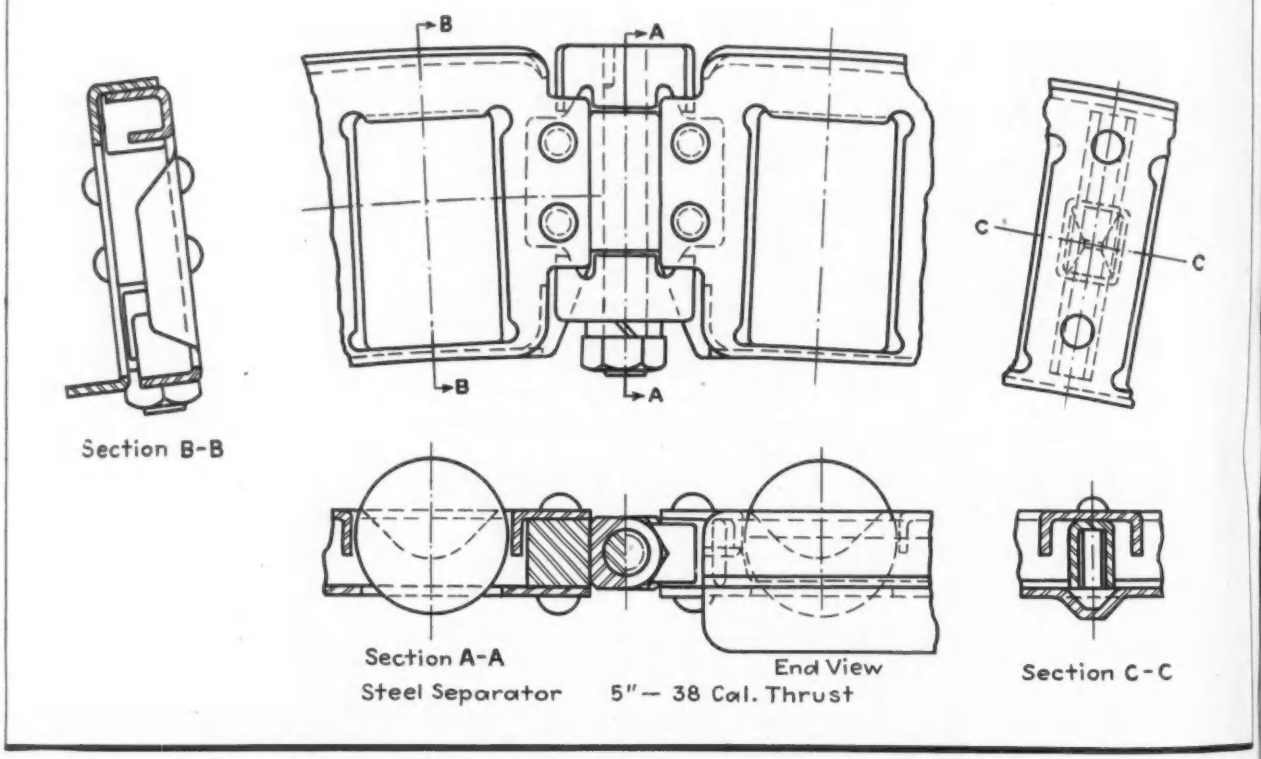
completed separators direct to the various prime contractors for assembly into gun mounts. Inspection is centralized at one plant, thus eliminating duplication. The Miehle Press Company and Applied Arts Corporation offered helpful suggestions during this development.

In this article, S. R. Thomas, chief engineer of the Bantam Bearings division, details the design improvements in three types of separators. As a result of this successful development, the bronze separators of the Bofors 40 mm. twin mounts will be replaced with separators of stamped steel.

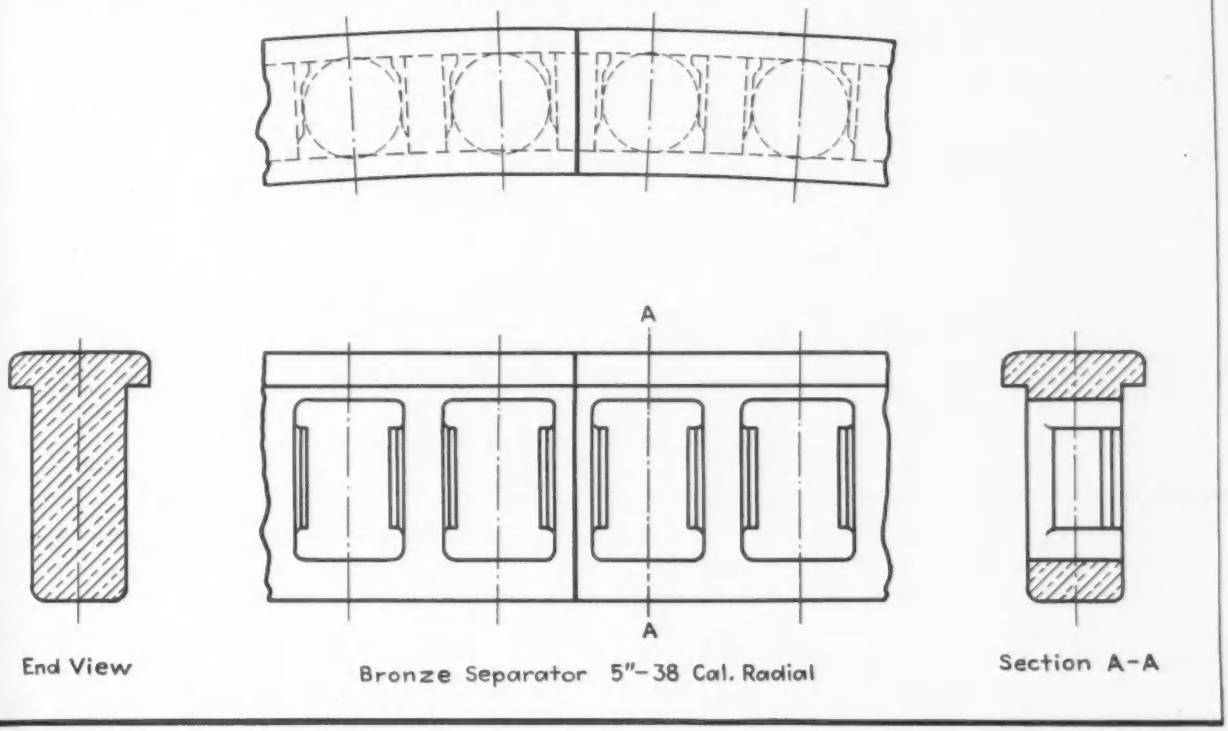
FINISHED SEPARATOR WEIGHTS

Gun Mount Bearing	Bronze	Steel	Weight Saved	Percent Weight Saved
5"-38 Thrust	176	54	122	69.3
5"-38 Radial	92	36	56	60.09
3"-50 Thrust	12	4.5	7.5	62.5
3"-50 Clip	16	7.0	9	56.1

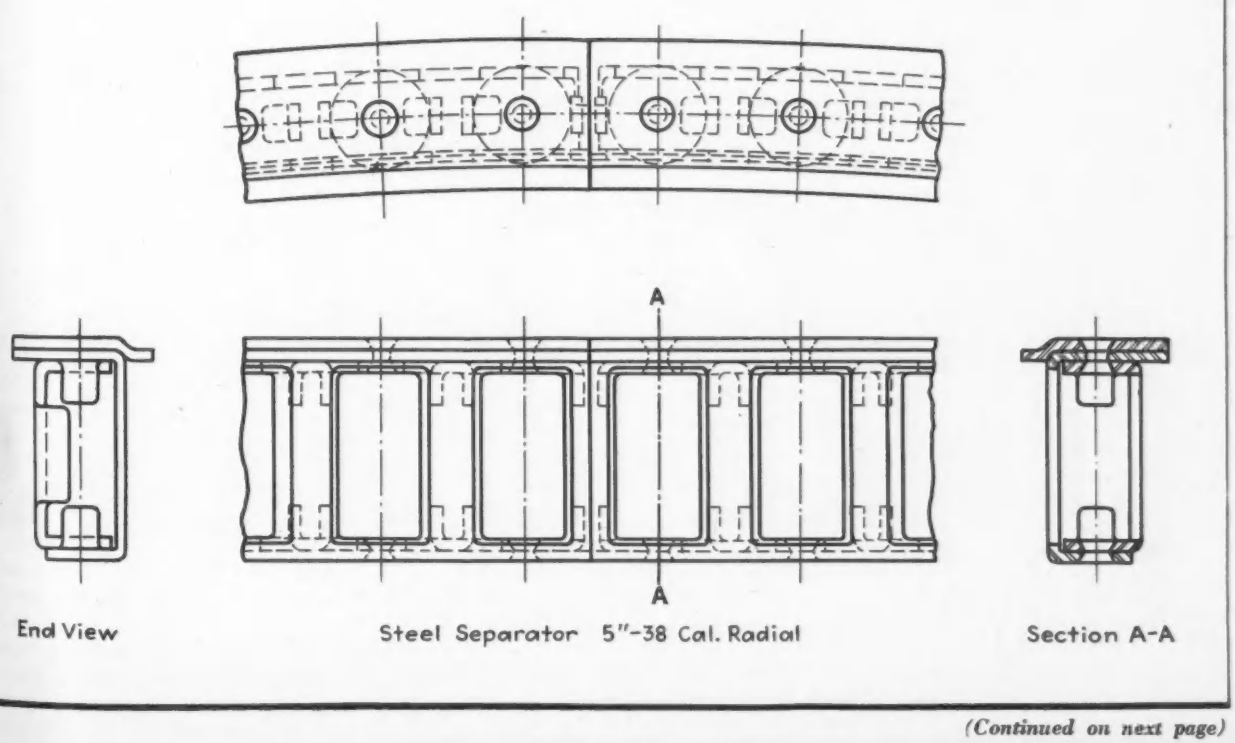




New design of thrust and radial separators for the 5 in.-38 caliber single gun mount is of stamped steel. Thirteen-gage metal is used for both top and bottom stampings to insure rigidity. Thrust separator, complete with eight sections and clamp assemblies, weighs 54 lb. Thus a weight saving was made in this one thrust separator of 122 lb. or almost 70 percent. The separator is not carried on the rollers, but rides on projecting shoes, stamped into the lower plate. Upper and lower halves are assembled with brass rivets separated by inverted "U"-shaped spacers. No top projections are required on this separator to prevent "floating" since roller pocket perforations in the lower stampings are narrower than roller diameter. Rollers, being straight, tend to run tangent to roll paths of the races. Therefore flat contact surfaces are provided for the outer end as well as both sides of each roller. These are formed lips. Parts are heavily zinc-plated before assembly. If plating is done after riveting, there is a probability of electrolytic reaction. Steel cage is guided in same way as bronze cage. concentricity is maintained with race rings by means of a vertical flange.



Radial separator for 5 in.-38 caliber mount in bronze and pressed steel, respectively. This development followed the approval of the thrust separator and is closely related in design to that of the latter. The rollers at assembly are kept from sliding completely through their pockets to the outside by narrower perforations in the outer stamping. The bronze separator, shown above, is made in four sections weighing 35½ lb. each as cast, or a total of 112 lb. per bearing. After machining, this weight was reduced to 92 lb. per bearing. The pressed steel assembly illustrated below is made in eight sections of 4½ lb. each, or 36 lb. per bearing, a saving in weight of 56 lb. or 61 percent.



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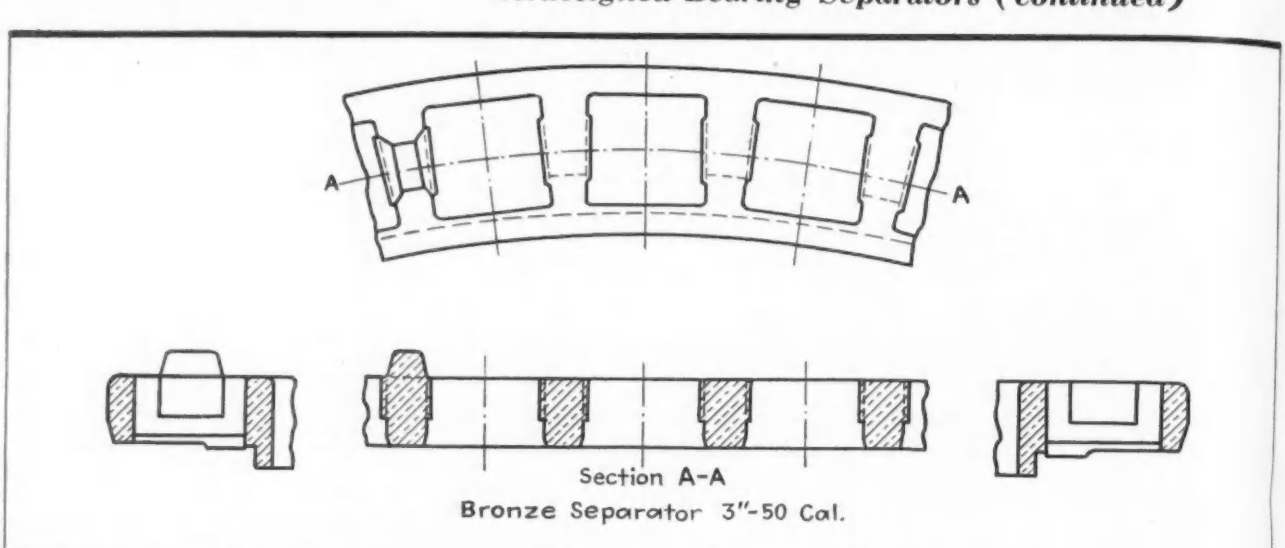
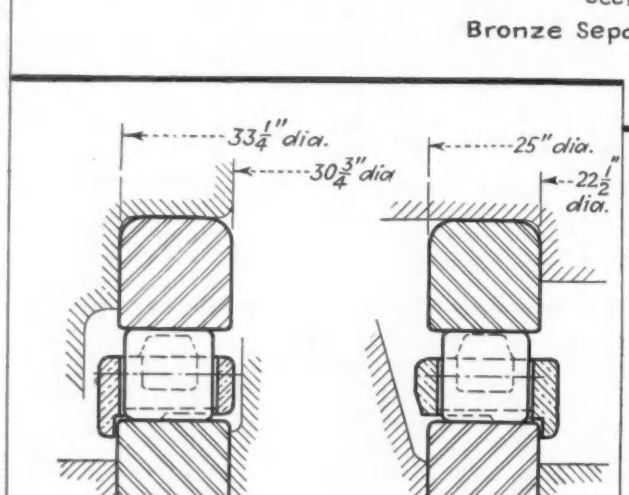
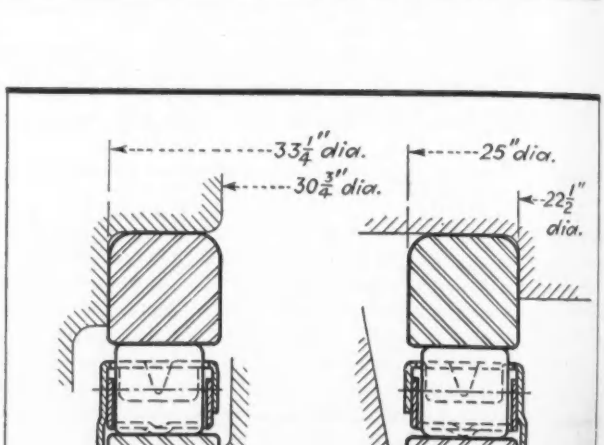
Redesigned Bearing Separators (continued)



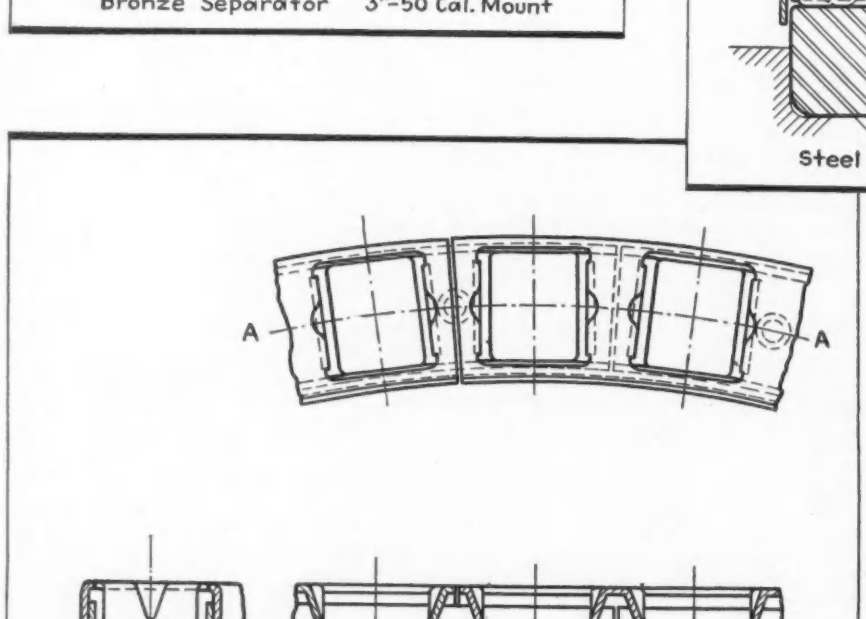
Bronze Separator 3"-50 Cal.



Bronze Separator 3"-50 Cal. Mount



Steel Separator 3"-50 Cal. Mount

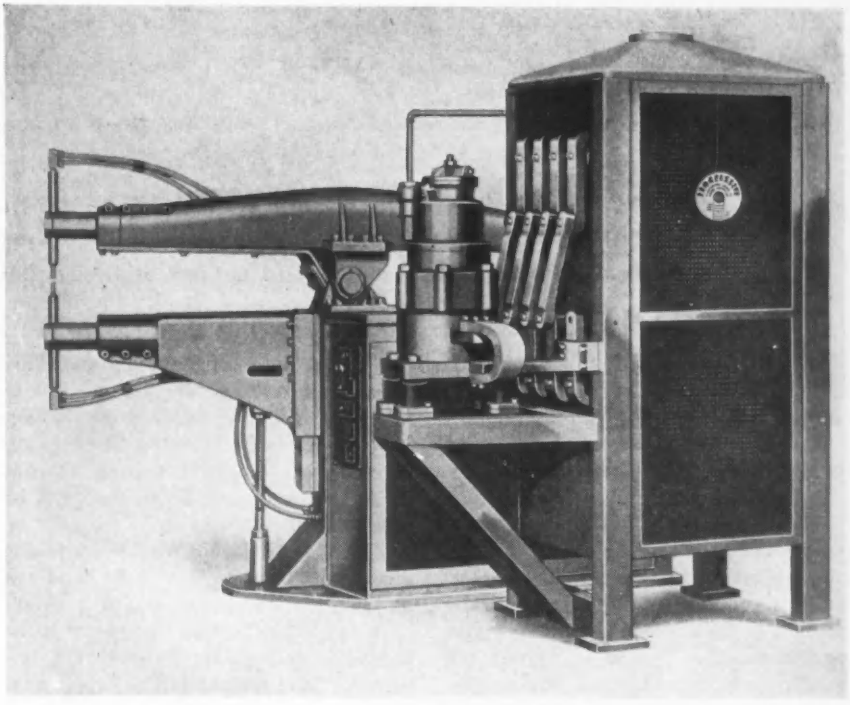


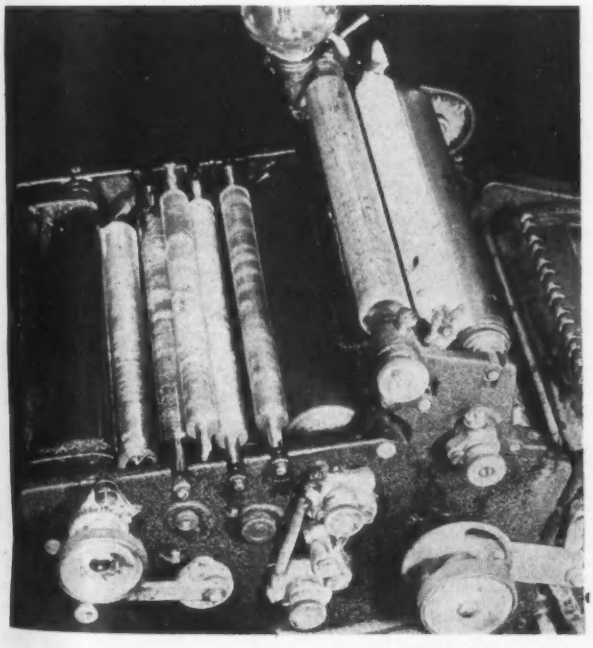
Steel Separator 3"-50 Cal.

Approximate relationship of the thrust (inner) and clip (outer) bearings with bronze cages as used in the 3 in.-50 caliber gun mount, shown above, and the same bearing with the pressed-steel separators, shown below. Separators are made in several sections as stampings and alternate top and bottom sections are staggered at assembly to provide joining. These overlapping sections are welded together. All parts are heavily zinc-plated. The larger, or clip-bearing separator in bronze weighs 16 lb., the smaller 12 lb. In pressed steel, the larger weighs 7 lb. and the smaller 4½ lb. thus saving 9 lb. and 7 lb., or 56 percent and 62 percent respectively. Stampings are made from 16-gage stock.

Resistance Welder Powered by Storage Batteries

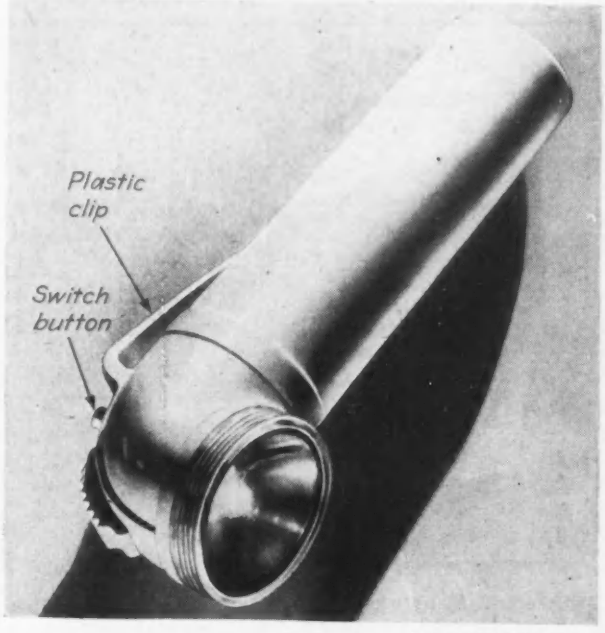
Developed for welding aluminum aircraft assemblies, this Progressive Welder unit uses new-type batteries as a source of stored energy. Success of the new design depended on availability of heavy-duty batteries and development of an accurate method of interruption and control of current. The new type of battery used is similar to a special battery developed to meet certain Naval requirements. Current is varied by a contactor-controller operating on pressure adjustment. Basic principle is that of the "carbon-pile." When air pressure on the contactor drops to zero, current automatically stops flowing, thus it is possible to interrupt welding current without arcing. Voltage drop from battery to electrode is only a fraction of that between the same electrode and conventional welding transformer. Power to keep batteries charged is supplied through a dry-disk rectifier having automatic controls, connected to conventional a.c. power line.





du Pont de Nemours Co.

Ink distributing rollers of transparent methyl methacrylate are successfully replacing rubber rolls on duplicators and offset presses. Precision machining and grinding insures accurate dimensions. Rollers, made by Lumirol Company, are cleaned easily and quickly. They are interchangeable with conventional rubber rolls.



Tennessee-Eastman Co

Waterproof plastic case molded of cellulose acetate will withstand 24 hr. immersion tests. This new design has twenty-two parts as compared with the thirty-six in the former model. Flashlight, styled by Dohner and Lippincott for Allbright Electric Company, has plastic belt clip, and switch button located on right-angled top.

Induction Heating Advantages Warrant New Designing Techniques

FRANK W. CURTIS
Consulting Engineer, Induction Heating Corporation

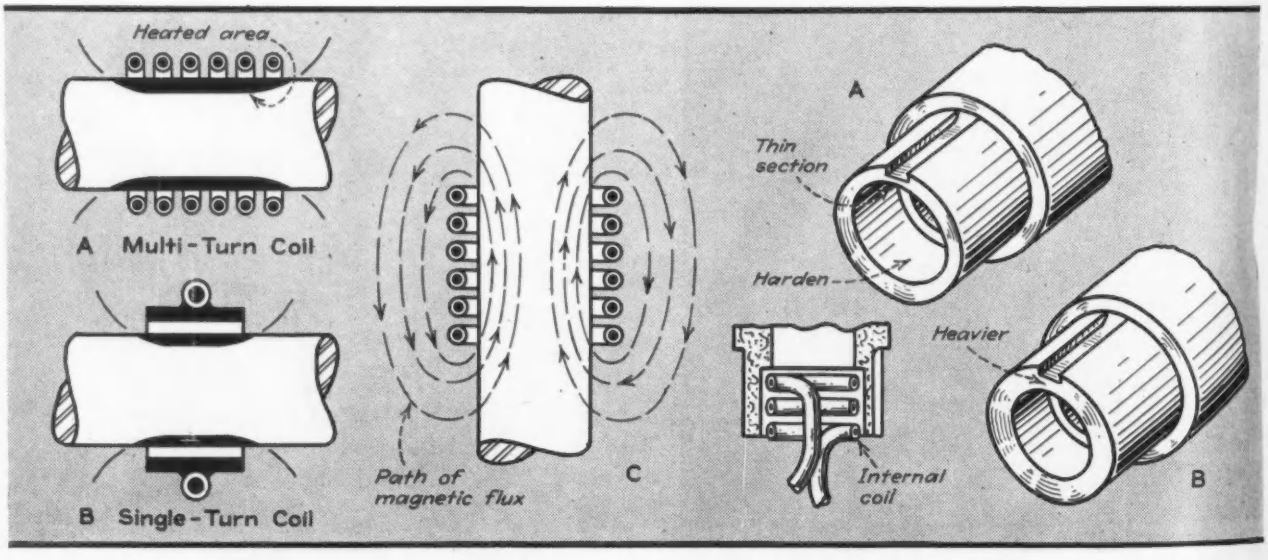
Economical, uniform heat applied rapidly to localized areas will tend to simplify manufacturing processes and contribute to improving products. Design modifications are often necessary to permit high-frequency heating operations.

HIGH-FREQUENCY induction heating, for hardening, brazing and soldering, unquestionably is having a marked effect on manufacturing methods. To obtain the best possible results in the application of induction heating it is sometimes necessary to modify the design of the part to suit the characteristics and practical requirements of this method of heating. Usually changes are not drastic but merely slight modifications in order to permit the high-frequency induction heating operation to be carried out more efficiently and effectively.

A sound general knowledge of what induction heating can and cannot do is basic to its successful application. This knowledge is relatively simple, but is necessary if the full benefits of induction heating are to be utilized. In checking cases where induction heating has not produced exactly what was wanted or expected, the cause could usually be traced to some design feature or details which could easily have been modified at the time the design was originated.

In induction heating, the metal to be heated is surrounded by one or a few turns of pure copper tubing, a substantially uniform and narrow air space separating the metal from the coil. Only the metal in proximity to the coil is heated when high-frequency current passes through the coil. The heating is produced by the high-frequency magnetic field inducing eddy currents in the metal. The rate of heat generation is proportional to the density of the magnetic field and its frequency. Generally speaking, the only limitation in the application of induction heating lies in the possible difficulty or practical impossibility of making a heating coil or inductor that will properly fit the surface of the part requiring heat, or the lack of a high-frequency generator with sufficient output power to heat adequately the surface or surfaces in question.

Since localized surfaces can be hardened inductively without heating adjoin-



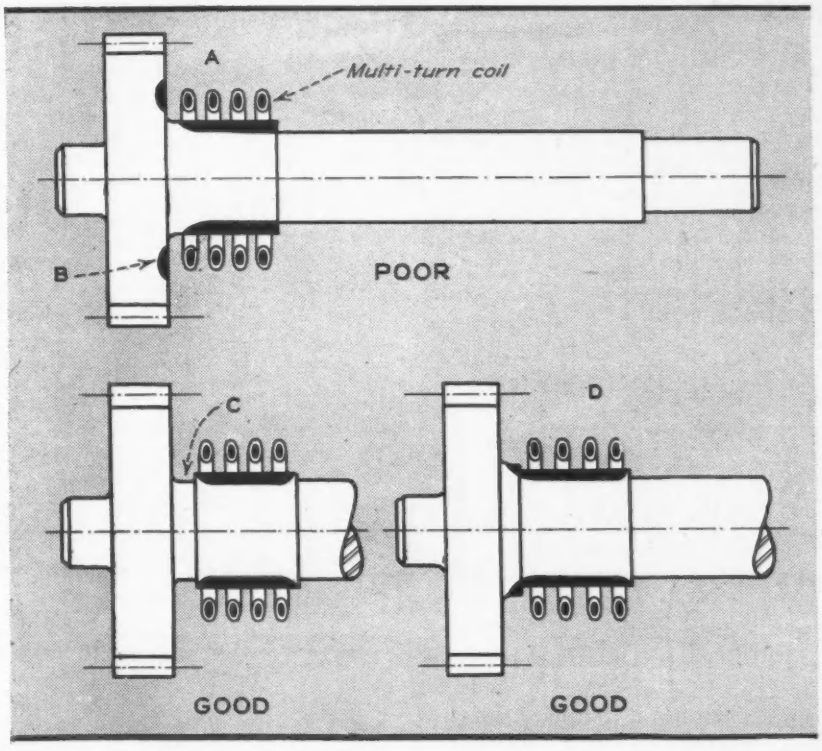
Induction heating coils can be multi-turn as shown at (*A*), or single-turn as at (*B*). Between the two types, any multitude of shapes and styles can be arranged to heat outside, inside, flat and irregular surfaces. Magnetic lines of forces surrounding a coil, as at (*C*), theoretically are equal in all directions from the centerline of the coil. Their density is less outside than inside the coil, and, likewise, their density varies inversely as the distance from the part to be heated and coil is increased.

Thin surfaces are liable to become overheated through induction heating before adjoining heavier sections have received sufficient heat. The end of the shaft at (*A*), requiring hardening on the internal hole, would result in the generation of excessive heat through the thin section before the remainder of the hole reaches the proper quenching temperature. By adding more metal between the hole and the bottom of the keyway, as at (*B*), a more nearly uniform heat will result and the danger of burning is avoided.

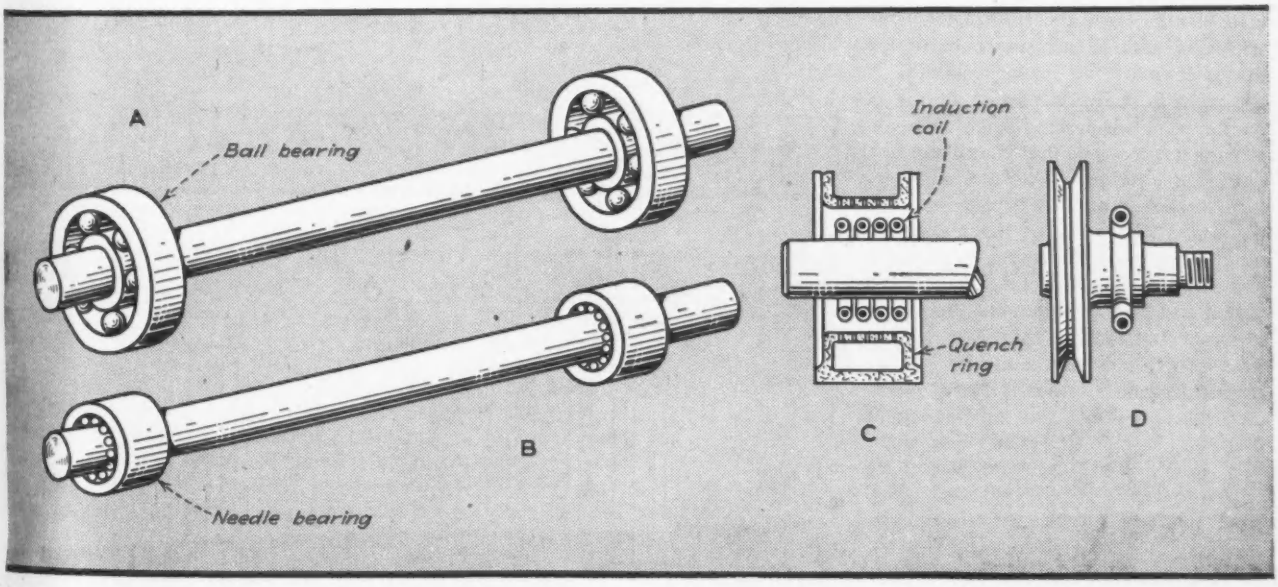
ing areas, the application of induction heating is going to result in new designing techniques. In some cases, improved products will be made available, in others it will be possible to obtain results that ordinarily would be impossible or too difficult to achieve by other means. There also will be the simplification of manufacturing processes, such as the elimination of carburizing by substituting higher carbon steels, and also the fabrication of parts from two or more sections in place of a one-piece design which might necessitate difficult machining set-ups.

Design for induction brazing sometimes requires special consideration, yet joints of a wide range of conventional design can be made effectively without modification. The basic consideration is to analyze the parts to be joined to determine if more heat is needed at one section than another, and then design the heating coil to suit the application. Occasionally to heat light sections it is better not to heat directly but to allow the heat to flow by conduction from a heavier section. Sometimes it may be necessary to modify the shape of the part.

High-frequency induction heating has many uses in all types of industrial plants and its application undoubtedly will play an important part in our postwar era. As is true of any new process, it is necessary to follow certain fundamental designing procedures.



Surface heating by the induction method of a shaft adjacent to a shoulder shown at (*A*). It is difficult to obtain heat in the fillet or corner since some of the flux energy from the end of the induction coil flows into the face of the flange, as indicated at (*B*). This condition results in a "cold spot" at the fillet, which can be heated only by conduction, requiring more heating time. Increased heating time might result in excessive heating at other portions of the work. This condition can be improved easily by adding a relief, as at (*C*). If a slight shoulder is desired, such as for needle bearings, the design at (*D*) can be substituted so that heat will be generated in the sharp corner.



Substitution of needle bearings for ball bearings was desired in the design of a machine shaft to operate in antifriction bearings where space was a limiting factor. Former design, shown at (*A*), could not be used because two parallel shafts were operating on close centers. Substituting the design shown at (*B*), it was possible to harden selectively the bearing surfaces, using the heating coil and quench ring illustrated at (*C*). The shaft, made of 0.50 carbon steel, is hardened to 62-64 Rockwell C, suitable for a needle-bearing race, and since heating is localized the usual straightening and cleaning operations, which ordinarily might be required, have been eliminated. This same means of induction hardening can be applied to races for ball bearings, as shown at (*D*), eliminating difficulties that might arise as a result of through-heating of such a part.

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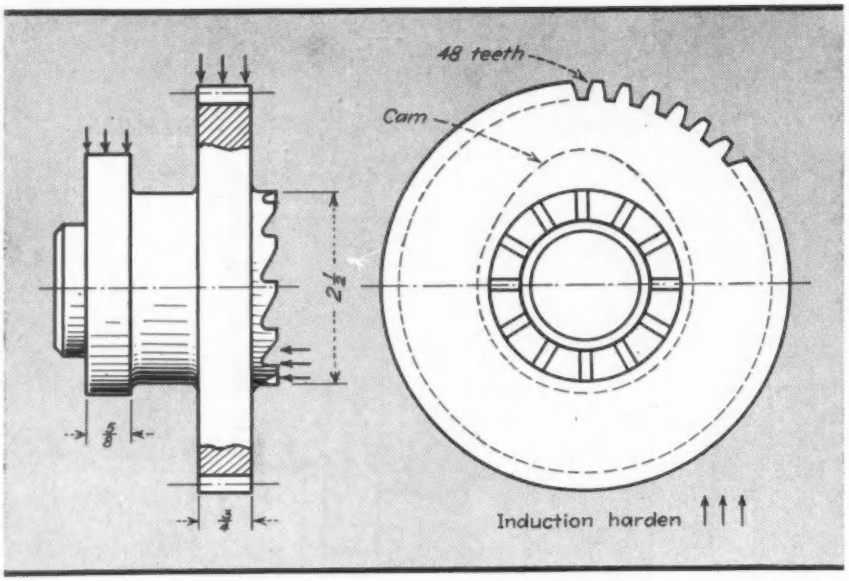
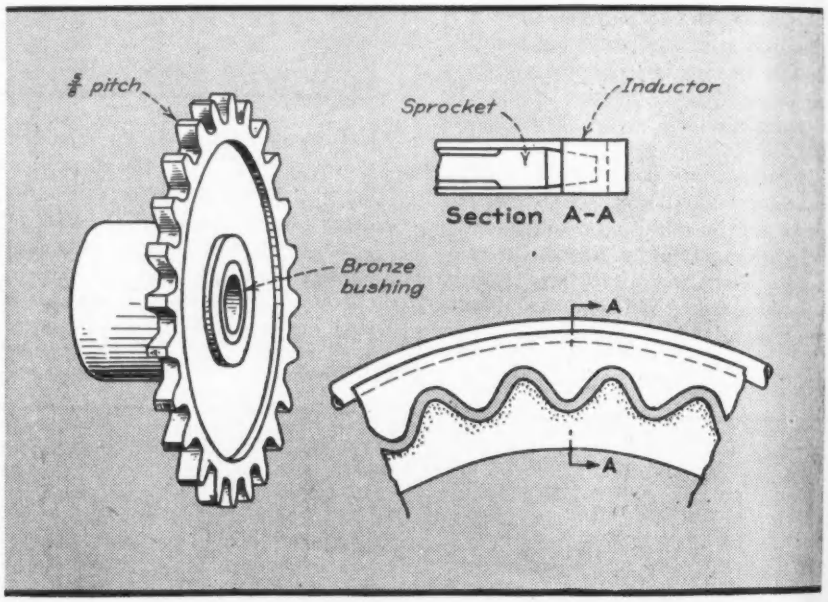
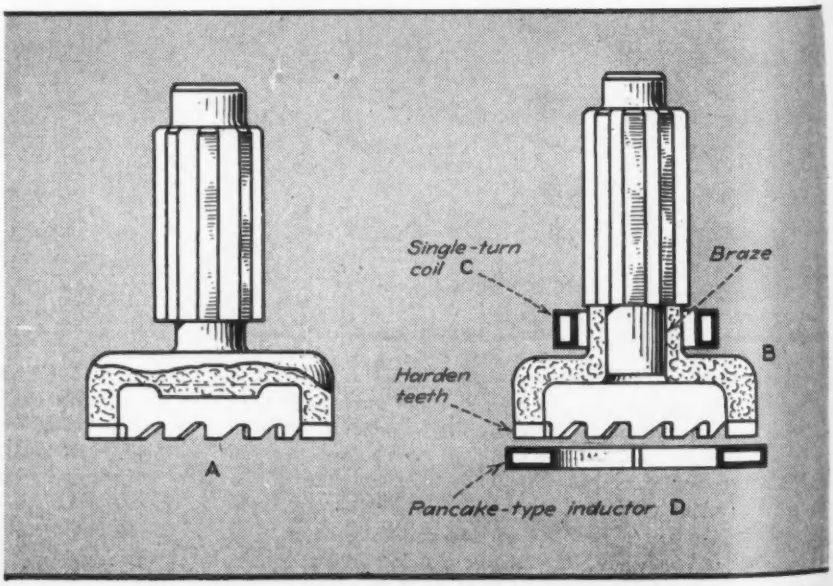


Three separate induction heating operations are performed on the gear to demonstrate how induction heat makes it possible to obtain different hardnesses on a single piece. Cam surface is hardened to 60-62 Rockwell C, in order to give the desired maximum resistance to wear. Gear teeth are hardened to 53-55 Rockwell C, whereas the clutch teeth are hardened to 48-50 Rockwell C to resist wear and withstand shock without fracture. Such modifications in hardnesses are obtained by slight variations in heating and quenching cycles, which automatically are timed so that uniformity is maintained.

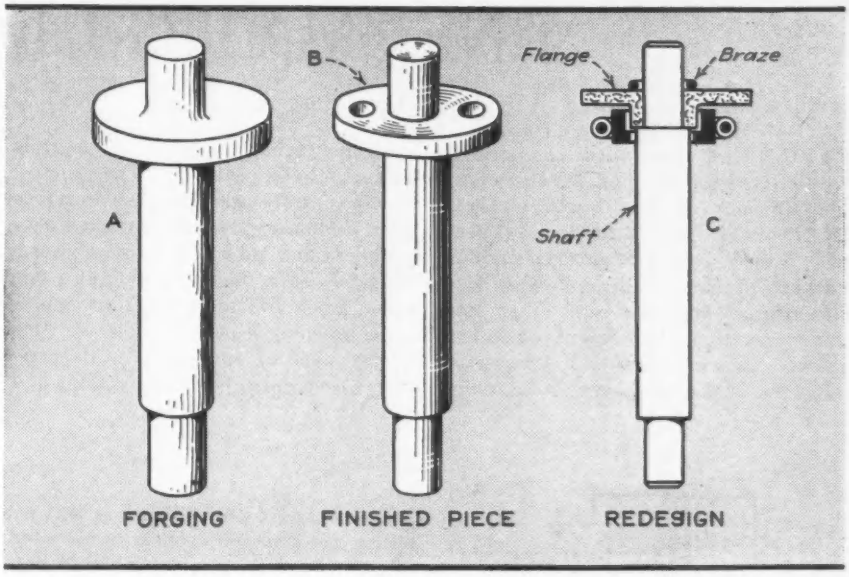
Manufacturing economies through the application of induction hardening is exemplified in the modified design of this sprocket. Formerly, the sprocket was carburized and required rough machining, copper plating, remachining to remove copper plate, cutting of teeth, carburizing, hardening, chucking from pitch circle of teeth to grind hole, and assembling of bushing. By using a higher carbon steel and induction heating, the new processing requires only machining of blank, assembly of bushing, cutting of teeth and induction hardening of teeth. Since the teeth are cut after assembly of the bushing, concentricity is assured and more easily obtained than by the former method. At the right is shown a portion of the inductor, which is formed to suit the contour of the teeth so that a uniform heat pattern is obtained. With a circular coil an excessive amount of heat would be generated at the top of the teeth. The elimination of carburizing, such as in this example, has a broad field of application and clearly points out the advisability of considering induction heating in connection with the design of mechanical parts.

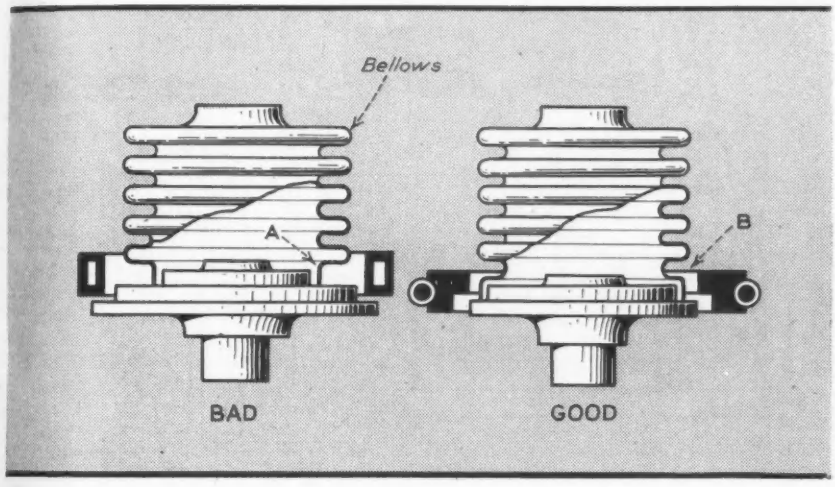


Clutch shaft is made in one piece, (*A*), and the two-piece design is shown at (*B*). Induction brazing is by means of the single-turn coil, (*C*), whereas hardening of the clutch teeth is by means of the "pancake" coil (*D*). Inasmuch as the heat required for hardening the teeth is strictly localized, there is no danger of the previously brazed joint being reheated.

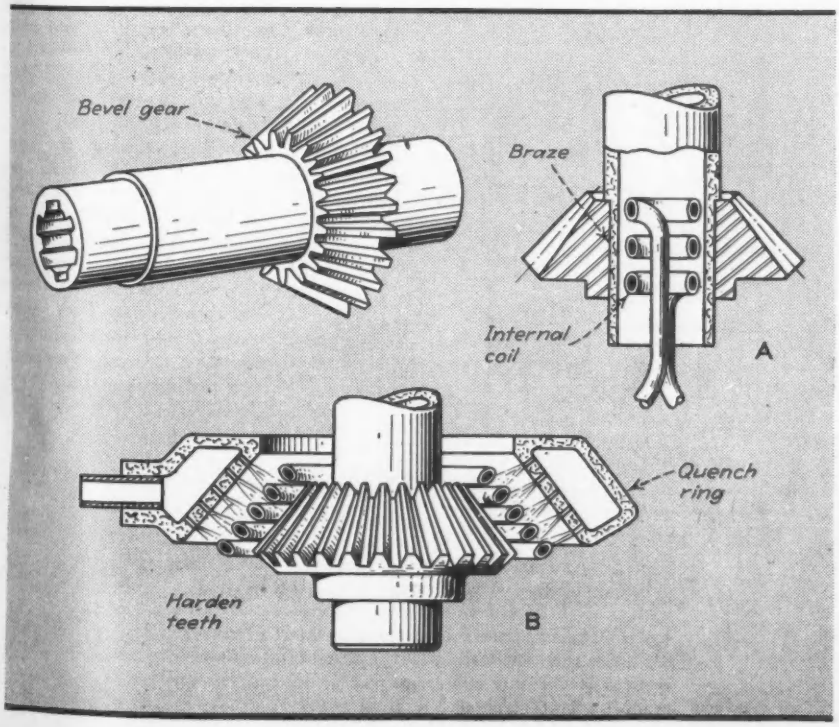


Induction heating-brazing makes possible the simplified design of the flanged shaft shown. It was made formerly from the forging (*A*), requiring machining of the flange profile as an integral member, as at (*B*). At (*C*) is shown the two-piece design, the flange being a stamping which is brazed to the shaft. The single-turn inductor, used for alloy brazing, is shown in its relative position during the joining operation. A ring of brazing alloy is placed at the joint, as shown, and a smooth, perfect joint is obtained within a few seconds from the time the high-frequency current is applied.





Bellows design was changed to permit joining by induction heat. In the design at (*A*), the coupling from the coil to the surface requiring soldering is too great, resulting in heat dissipation to the outer surfaces only. By revising the design so that the joint is at the outside edge, as at (*B*), heat can be applied precisely to the desired surface.



Two-piece design of bevel gear requires brazing and hardening. The teeth of the gear would be difficult to cut as an integral member of the spindle. Likewise, since the gear teeth must be hard, any form of brazing after hardening might result in annealing or drawing. By the induction heating method, the brazing of two parts is done by an internal coil, as shown at (*A*), which is followed by hardening of the teeth, (*B*), using a multi-turn coil which limits heat to the teeth only. A spray quench follows the heating portion of the cycle, and the entire hardening operation is completed at a rate of three pieces per minute.

PNEUMATIC CIRCUITS AND

PROPERLY controlled compressed air is a good medium for automatic and sequence operations where clean, dry, non-hazardous conditions must prevail. Processing, mixing, packaging, marking of foodstuffs, explosives, textiles, fragile materials, and other machine operations are being controlled quickly and efficiently by pneumatic cylinders. The accompanying diagrams illustrate various types of air controls on double-acting cylinders. The exhaust-type of control system requires no return piping. Master valves are mounted near cylinders and pilot valves are convenient for hand or foot operation at a distance. These and additional illustrations in subsequent issues will give an idea of the scope of applications. Air pressure, speed, duty cycle of operations and general conditions are factors capable of being varied to suit individual requirements. Layouts are typical of possible applications encountered by Ross Operating Valve Company. Advantages and limitations of pneumatic circuits were given in further detail on pages 255-7 and 318-21 June and July, 1940, and pages 174-7 March, 1944, PRODUCT ENGINEERING.

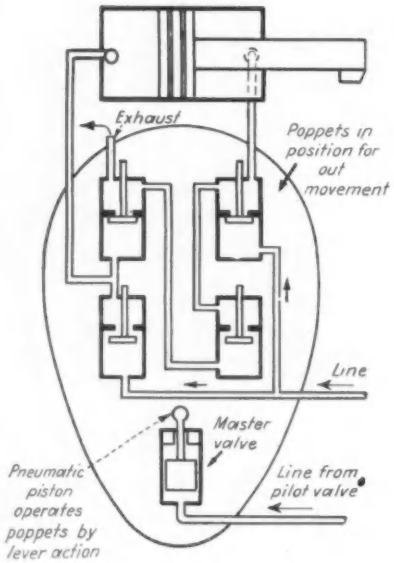
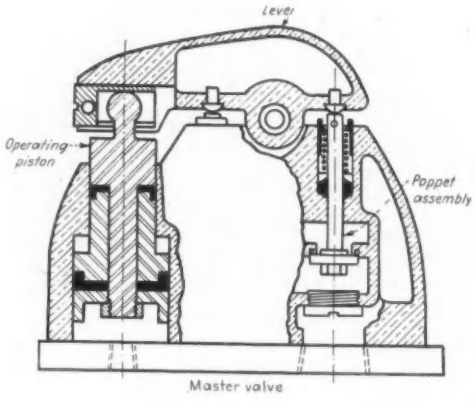


Fig. 1—Master valves *MV* consist of 4 poppet valves, which can all be closed or are opened by pairs for out and back strokes in cylinder, and a pneumatic piston for operating poppets by lever action. Some master valves are designed for manual and electrical operation.



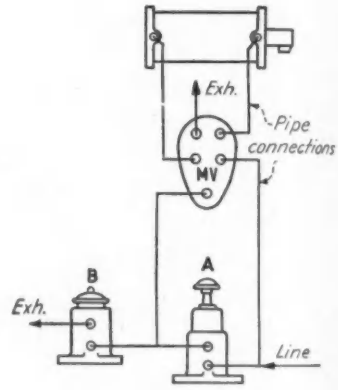


Fig. 2—Simplest piping layout for controlling out and back strokes of a pneumatic cylinder. Pilot valve *A* supplies air pressure to master valve operating piston, which opens air circuit for out stroke. Pilot valve *B* releases air in the operating piston, which opens the air circuit for return stroke. These two pilot valves may be combined in one three-way valve if desired. Convenience of valve locations is the determining consideration in valve selection.

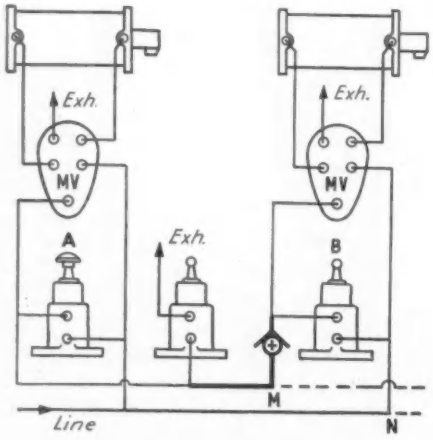


Fig. 3—Two pneumatic cylinders may be operated in various combinations of movements. Simultaneous strokes, either in the same or reverse directions, can be handled by one master valve. Independent operation requires two master valves. This circuit gives independent out strokes by means of pilot valves *A* and *B*, and simultaneous back strokes by pilot exhaust valve releasing air pressure in both master valve operating pistons. Valve *B* will also give simultaneous out strokes if *A* has not been operated.

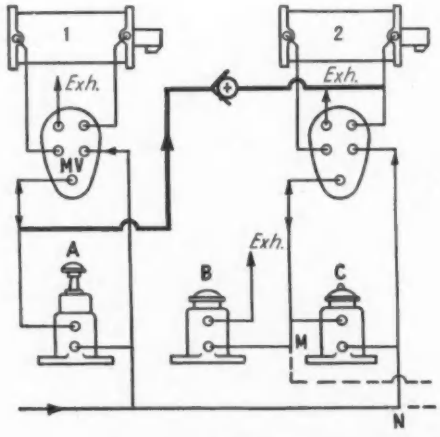


Fig. 4—Another combination of two pneumatic cylinders employs the same valves as in Fig. 3 with a slightly different piping layout as indicated by the heavy lines in each diagram. Valve *A* controls the out stroke of cylinder 1, valve *B* returns No. 1 and makes an out stroke in cylinder 2, and valve *C* returns No. 2 cylinder.

TYPICAL APPLICATIONS

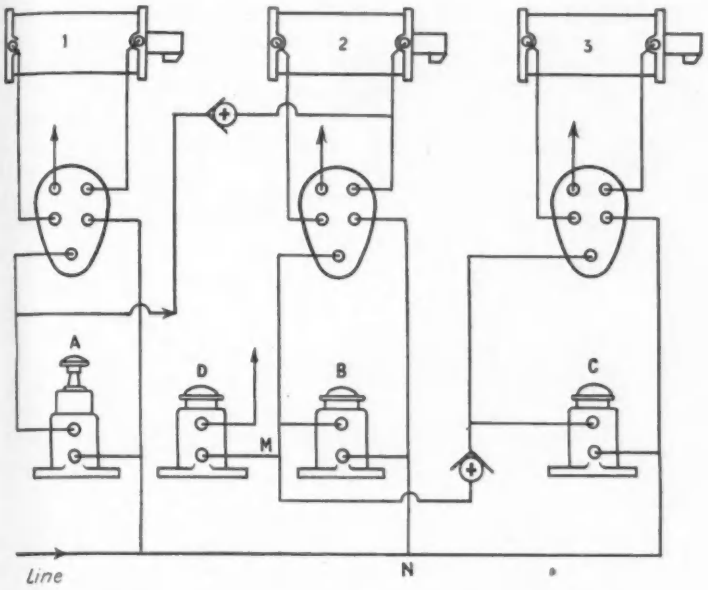


Fig. 5—Increase to three cylinders further increases possible combinations of operation. One or more units can be added to Fig. 3 layout merely by opening the line at points *M* and *N*. Fig. 5 duplicates Fig. 4 with an added unit and check valve connected at points *M* and *N*. In this layout *A* puts No. 1 out, *B* puts No. 1 back and No. 2 out, *C* puts No. 3 out, and *D* puts Nos. 2 and 3 back.

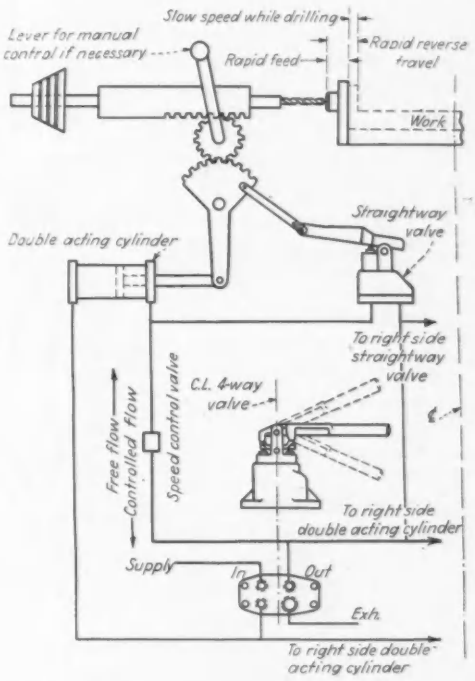


Fig. 6—Automatic drilling operation has three speeds: (1) Rapid feed of drills to points of contact with work; (2) slower speed during drilling as the result of straightway valves mechanically operated at the point of contact, which close bypasses around speed control valves; and (3) rapid reverse stroke. Right half is duplicate of left except for 4-way valve.

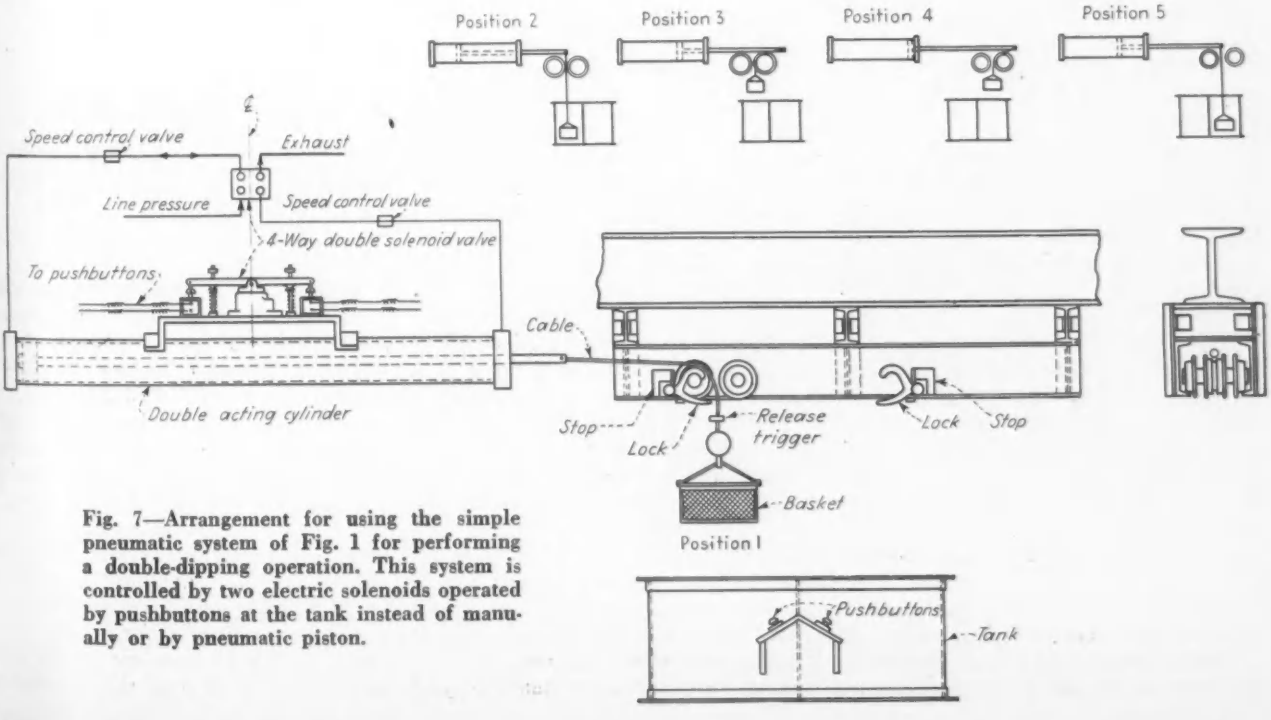
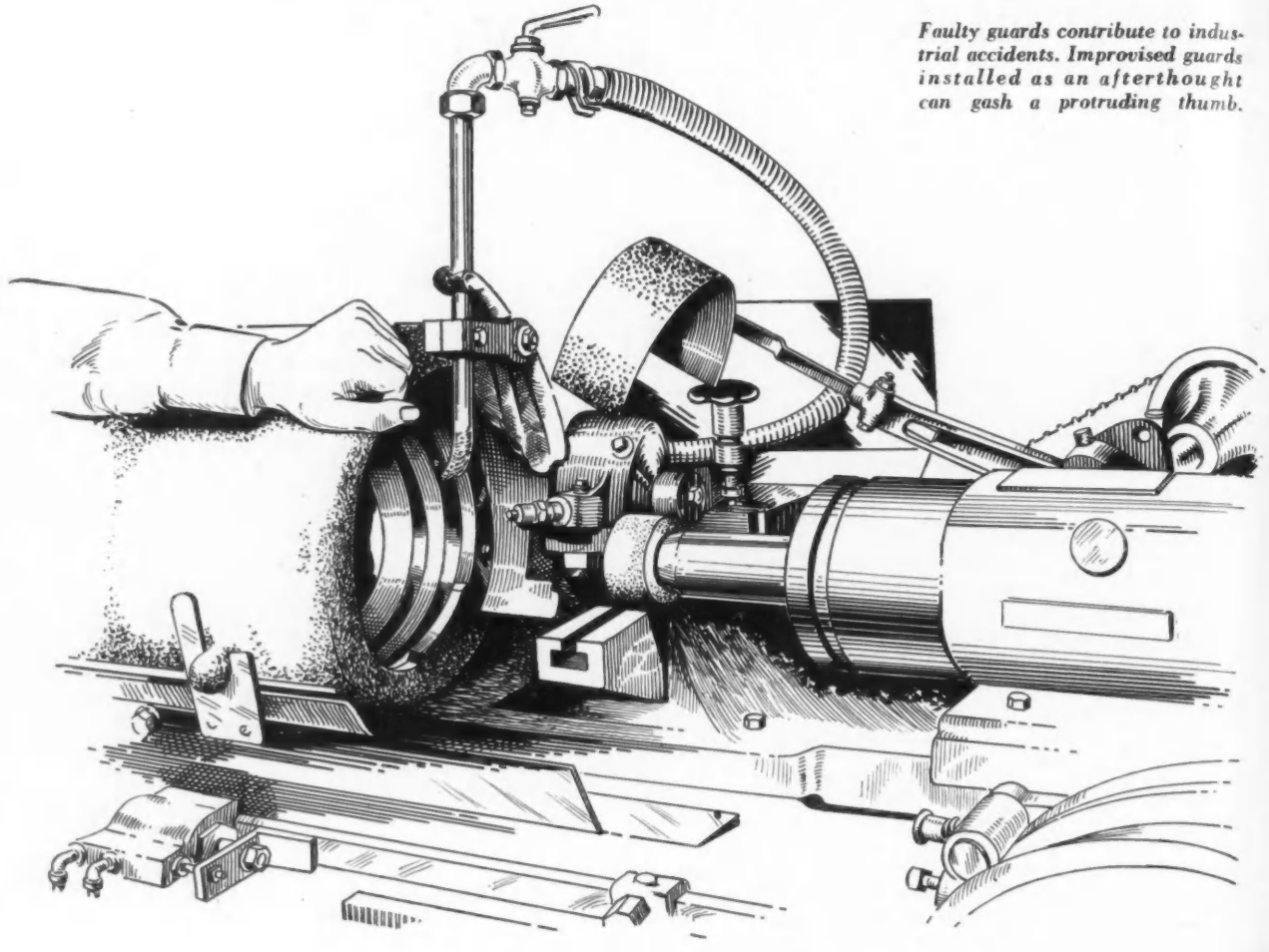


Fig. 7—Arrangement for using the simple pneumatic system of Fig. 1 for performing a double-dipping operation. This system is controlled by two electric solenoids operated by pushbuttons at the tank instead of manually or by pneumatic piston.



Faulty guards contribute to industrial accidents. Improvised guards installed as an afterthought can gash a protruding thumb.

Safety Considerations Urged In Design of Production Machinery

FREDERIC L. STAFFORD

IT IS not the safety engineer's job to tell the designing engineer what to do. But if the average designer could leave his drawing board and take over the job of a safety engineer for just a few weeks, his next machine would, undoubtedly, present some startling departures from his previous designs. Even a cursory study of the design of virtually all production machinery clearly shows that the machines are designed almost exclusively for maximum production, with little attention to safety features. Strictly speaking, the major criticism that can be aimed against the design of modern production machinery is not the lack of safety features but rather the numerous and totally unnecessary unsafe features in the design.

Perhaps the most ironical fact with reference to the design of production machinery is that maximum production over the long run is obtainable only when the machine is easy to maintain, when the operator need not exert exclusive caution in the operation of the machine to avoid injury to himself. Innumerable investigations prove conclusively that an operator soon grows tired and irritable if the design of the machine is such that he must be constantly on the alert to avoid an accident. This, naturally, cuts down his production.

Machine accidents, and the fear of them, place a definite limit to the output of an otherwise well-designed unit. The most common faults from the safety angle in the design of machines include exposed moving elements that might crush the hands or fingers, arrangements that require awkward movements when feeding or operating the machine, and poor design of guards. Investigation often reveals that guards are added accessories improvised by the operator of the machine and not incorporated in its original design.

Many safety devices fail because they were afterthoughts tacked on the machine here and there like hanging ornaments on a Christmas tree. A glowing example is the practice requiring the machine operator to cover a dangerous spot with a homemade sheet-metal guard. Even though the guard serves its purpose, maintenance men are likely to leave it off because it is difficult to adjust or does not fit properly. Too often the so-called safety guard remains off until a finger has been amputated or some other injury suffered by a workman. Such conditions are all the more regrettable in view of the fact that in

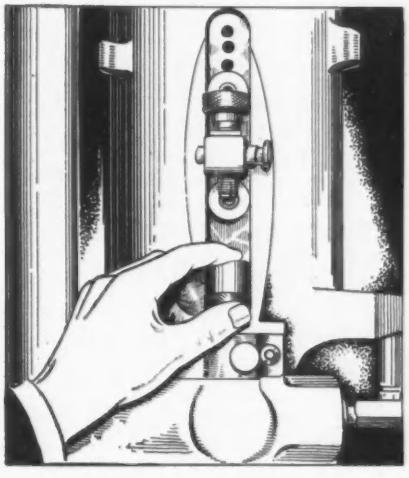
many instances if the machine had been designed with proper thought to safety, many hazardous points could have been eliminated and there would have been no necessity for guards.

The ideal machine is one in which every dangerous point has been eliminated by careful design and therefore requires no separable guards. This, of course, is an ideal that is not always obtainable but can be approached in every design.

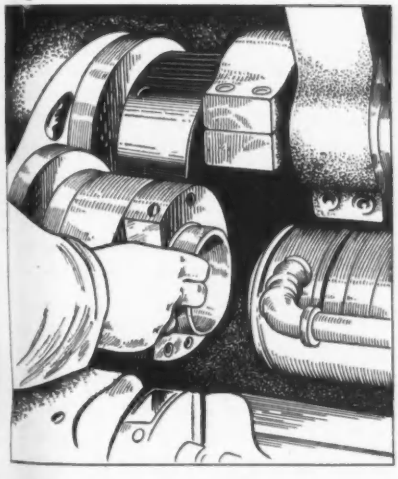
Guards should always be considered as an evil adjunct. Intensive study should be made to eliminate the point of hazard or incorporate the guard as an integral part of the machine in such a manner that it cannot operate without the guard being set. Any other type of guard is, in itself, a hazard because it is impossible to expect perfect adherence to rules that all guards must be in place before the machine is put in operation.

In most instances, a machine to which a guard has been added as an afterthought is easier to operate with the guard removed. One of the time-honored objections toward making a unit "too safe" through the use of guards is because the guards slow production. Incidentally, this is often true but only because the machine was designed originally to operate without guards, and hence the guards subsequently added prove to be superfluous insofar as the mechanical operation of the machine is concerned.

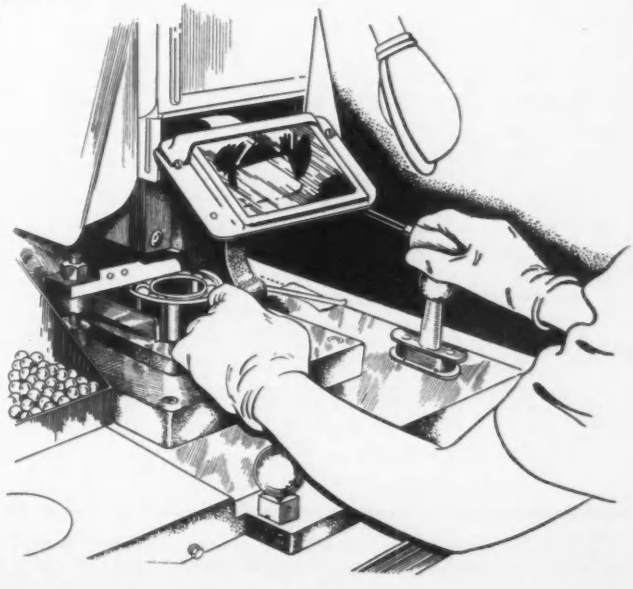
Few designers have the opportunity of seeing their machine operate in mass production. Accident hazards are not apparent when the machine is set up in the laboratory of the manufacturer and a few pieces are turned out under ideal conditions. But when the machine is installed in a shop and thousands upon thousands of pieces are made under the pressure of mass production, month after month, the points of hazard become obvious through regrettable accidents. Sooner or later dangerous places on the interior or exterior of the machine will contribute to a crushed finger, broken bone or perhaps an amputated limb. It is safe to assume that during the life of every production machine it is operated in every conceivable fashion and human hands come in contact with every square inch of its surface.



Manual positioning of a block in a pressure feed control device often proves hazardous. Safeguard for repositioning blocks is a design consideration.



Undivided attention on the part of the operator is necessary to avoid mishaps in using a machine similar to the one sketched. An indexing head carries several pieces of work through various operations. An inside chuck arrangement comes forward and removes the finished work. If the operator misses one sequence in feeding, he must remember not to reach into the empty chuck when it comes around or painful injury can result with resulting absenteeism.



Two-handled "safety" tripping device represents a typical press installation. This drawing shows how both handles can be moved easily and unintentionally. Operator's left forearm resting on handle can hold it in operating position and lead to a careless accident. This could have been overcome in original design if human factor was considered.

Over the past few years, the author has personally investigated nearly 300 accidents that resulted in varying degrees of physical injury. Some of these mishaps were extremely serious, and a few proved fatal. A careful study of the accident data proved conclusively that fully 49 percent of mishaps could have been avoided if certain simple safety features had been incorporated in the original design.

The greatest opportunity for the incorporation of safety features lies in the design of shop equipment machinery where the same type of work is being done continually as contrasted with standard basic shop tools for job shop work where something definite is being turned out almost daily. There is little or no excuse for hazardous features on machinery that has been specially designed for the mass production of a specific item. An appreciation of the following three points is important:

1. The human body is incapable of performing routine operations perfectly over any long period of time; 2. It is easier to eliminate hazardous points in the design of a machine than it is to remind each new man and "old-timer" of certain danger spots; 3. Any machine that requires a definite act by the operator to insure his safety is not a well-designed unit.

The commercial value of safe designs must not be underrated. The engineer who develops his designs with the operator in mind from the start, instead of thinking of the job the machine is to do, will place himself and his company in an advantageous position. Many customers and prospects recognize the cash value of safety. All other things being equal, the machine that is safest to operate will out-produce comparable units. New design features that contribute to the safe operation of the machine are often patentable.

Anti-Friction Bearing Selection For Varying Load Conditions

KENNETH N. MILLS
Works Manager, Texasteel Manufacturing Company

Engineering computations that enable better selection of anti-friction bearings for machines in which loads vary are exemplified with a hoisting machine for removing pipe from an oil well. The general considerations in bearing selection are also outlined.

THE application of anti-friction bearings in equipment where the loads vary involves the use of a special series of formulas giving a suitable load factor. If the bearing load varies over a wide range and the nature and magnitude of the load is accurately known, an accurate estimate of bearing life can be made with the resulting load factor, which is between peak load and the arithmetical average load.

This method of bearing selection is based on the assumption that bearing life varies with the cube of the load, as indicated by the following equations from SKF Steel Mill Data for Calculation and Design. The exact value of the exponent is debatable, however. Values from 3 to 3.33 have been used by various authorities.

For constant speed

$$P = \sqrt[3]{P_1^3\, t_1 + P_2^3\, t_2 + - - - P_n^3\, t_n} \quad (1)$$

For variable speed

$$P = \sqrt[3]{\frac{P_1^3\, t_1 N_1 + P_2\, t_2 N_2 + - - P_n^3\, t_n N_n}{t_1 N_1 + t_2 N_2 + - - - - - t_n N_n}} \quad (2)$$

For average speed

$$N = \frac{t_1 N_1 + t_2 N_2 - - - - - - t_n N_n}{T} \quad (3)$$

Where:

P = root mean cube load
P_1 = load acting during time interval t_1 at N_1 r.p.m.
P_2 = load acting during time interval t_2 at N_2 r.p.m.
t = time interval during which loads act, minutes
T = total time interval, minutes
N = r.p.m.

The application of these formulas to a hoisting machine used to remove pipe from an oil well illustrates a design problem of variable load and speed. This machine consists of a wire rope reel drum driven from an internal combustion engine through a chain transmission system. The wire rope, which is attached to the drum, carries the load through a block, and a hook on the moving block carries the pipe load. Since this machine is used to remove several thousand feet of pipe from an oil well, it has a variable load cycle, that is the load varies as pipe is removed from the hole.

The pipe is made up of 30-ft. lengths connected by threaded couplings. Since the machine has a limited pulling capacity, the speed of withdrawal increases as the applied load decreases. Maximum pulling speed is about 300 ft. per minute.

To solve this problem it is necessary to measure or estimate variation of load and speed with time. The drum performance curve in Fig. 1 shows how line pull varies with drum speed. In this example

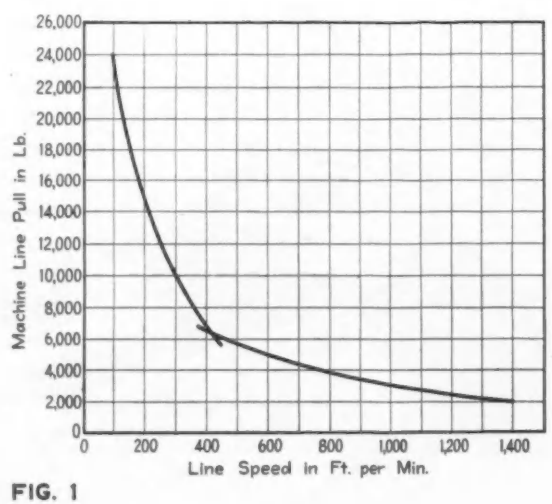


FIG. 1

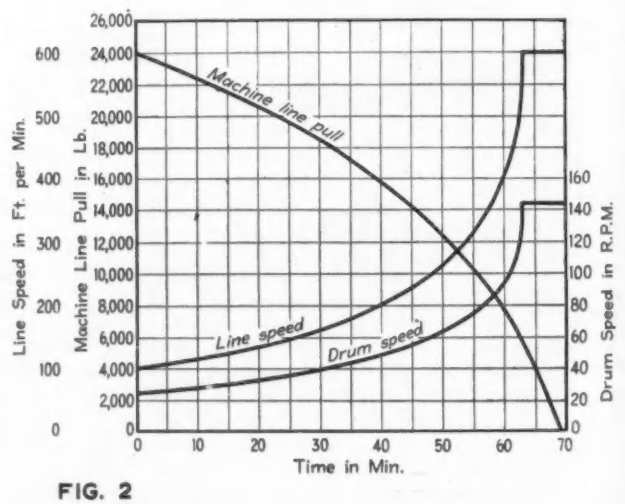


FIG. 2

Fig. 1—Drum performance curve gives average line speeds listed in Table I. Fig. 2—Results of computations shown in Table I give a performance curve from which to obtain load and speed for determining average loads.

Table I—Computations for Performance Characteristics

Line Pull at Start lb.	Line Pull at End lb.	Length of Pipe at start	Length of Pipe at end	Distance Pulled ft.	Average Speed ft. per min. Line	Average Speed ft. per min. Block	Time in Min. +15 percent	Average Drum Speed r.p.m.
24,000	22,000	6,540	6,000	540	100	50	12.4	23.9
22,000	20,000	6,000	5,450	550	120	60	10.6	28.7
20,000	18,000	5,450	4,900	550	140	70	9.0	33.4
18,000	16,000	4,900	4,360	540	170	85	7.3	40.6
16,000	14,000	4,360	3,820	540	200	100	6.2	47.8
14,000	12,000	3,820	3,270	550	230	115	5.5	55.0
12,000	10,000	3,270	2,720	550	275	138	4.6	65.7
10,000	8,000	2,720	2,180	540	325	163	3.8	77.7
8,000	6,000	2,180	1,640	540	390	195	3.2	93.3
6,000	4,000	1,640	1,090	550	562	281	2.3	134.0
4,000	2,000	1,090	545	550	600	300	2.1	144.0
2,000	0	545	0	545	600	300	2.1	144.0

Table II—Factors for Determining Average Load *

Average Load, lb.	Load / 2,000	Load³ / 2,000	Average Speed r.p.m.	Time min.	tN / (Time × Speed)	P^3tN / ((Load/2,000)³ × Time × Speed)
23,600	11.8	1,643	25.0	5	125	205,500
22,800	11.4	1,482	26.5	5	132.5	196,200
21,900	11.0	1,331	29.0	5	145	193,000
21,100	10.5	1,158	31,0	5	155	179,200
20,100	10.1	1,030	34.0	5	170	175,000
19,000	9.5	857	37.0	5	185	158,500
17,800	8.9	705	41.0	5	205	144,500
16,500	8.25	562	46.0	5	230	129,000
15,000	7.50	422	51.0	5	255	107,500
13,300	6.65	294	59.0	5	295	86,700
11,400	5.7	185	69.0	5	345	63,800
9,000	4.5	91	82.0	5	410	37,400
6,000	3.0	27	120.	5	600	16,200
2,000	2.0	8	144	4	576	4,620
				69	3,828.5	1,697,120

* Since these values are for one type of service, and the machine is used on several types of service, each type of service must be investigated to determine which imposes the most adverse loads on the bearings.

a pipe weighing 7.325 lb. per ft. is considered. Maximum length of this weight pipe that the machine can lift at an acceptable rate of speed is assumed to be 6,540 ft. Actual hoisting time is assumed to be 15 percent greater than theoretical time to allow for accelerating and decelerating the load.

To calculate the performance characteristics of the machine when operating under these conditions, a series of ranges of line pull starting with the maximum line pull were selected and tabulated in columns 1 and 2 of Table I. Average line speeds for each of these intervals were determined from the drum performance curve. Lengths of pipe in the hole at the beginning and end of each interval were determined by dividing line pull by the weight of pipe per foot and multiplying by the block multiplication ratio. Average time required to pull each 550 ft. of pipe was calculated by dividing the length pulled by average block speed. Results of these calculations are shown in Table I and expressed graphically in Fig. 2. The load and speed used to determine average load were obtained from this calculated performance curve.

The next step is to determine a factor with which to multiply peak torque load on the machine and thus obtain an average torque load that can be used in selecting anti-friction bearings. The calculated performance curve gives the average load and speed over small intervals of time and the magnitude of these time intervals. The average load can be determined with Equation (2). The factors $P^2\,tN$ and tN are given in Table II. Root mean cube average load is:

$$\text{RMC average load} = 2{,}000\sqrt[3]{\frac{1{,}697{,}120}{3828.5}} = 15{,}260 \text{ lb.}$$

The desired factor is:

$$\frac{\text{RMC average load}}{\text{Peak load}} = \frac{15{,}260}{24{,}000} = 0.636$$

The average speed for use in selecting bearings is determined by Equation (3):

$$\text{Average speed} = \frac{3828.5}{69} = 55.6 \text{ r.p.m.}$$

$$\frac{\text{Maximum speed}}{\text{Average speed}} = \frac{144}{55.6} = 2.59$$

To illustrate the application of these equations to a machine operating under a cyclic load at a constant speed, consider a single reduction speed reducer subjected to a varying load and having characteristics defined in Fig. 3. The reduction ratio is 5 to 1. In this example a factor for multiplying peak torque load is required to determine an average value of torque load which can be used in selecting anti-friction bearings. Since a torque factor is used, none of the equations can be used in their present form. Since the speed is constant and equal intervals of time can be selected, Equation (3) can be modified to eliminate the time values. Since the desired bearing load factor is a function of torque, the equation can be written:

$$\text{RMA average torque} = \sqrt[3]{T_1^3 + T_2^3 + - - - T_n^3} \quad (4)$$

T_1, T_2 — — T_3 = average torque during small equal intervals of time

The values of the slow-speed shaft torque, high-speed shaft torque, and high-speed shaft torque cubed are given in Table III for 10-deg. intervals of slow-speed shaft position. The mean of

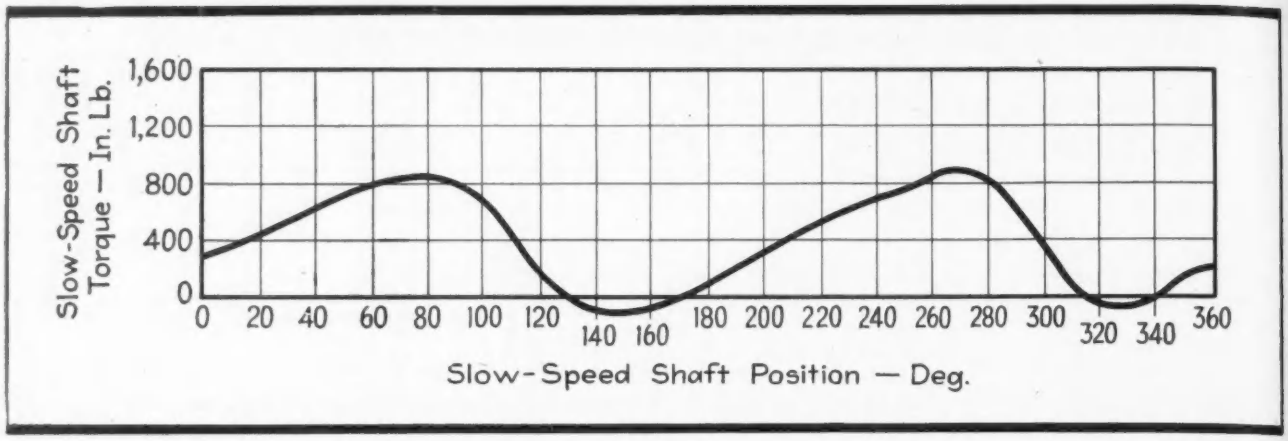


Fig. 3—Characteristics of a single reduction speed reducer, which is to be operated under a cyclic load at a constant speed.

Table III—Factors for Determining Average Torque

Crank Angle deg.	Slow-Speed Torque	High-Speed Torque	High-Speed Torque[3]	
0	+270	+ 54	+ 157,464	
10	350	70	343,000	
20	420	84	592,704	
30	500	100	1,000,000	
40	600	120	1,728,000	
50	720	144	2,985,984	
60	780	156	3,796,416	
70	830	166	4,574,296	
80	830	166	4,574,296	
90	800	160	4,096,000	
100	700	140	2,744,000	
110	450	90	729,000	
120	+180	+ 36	+ 46,656	
130	0	0	0	
140	−100	− 20	− 8,000	
150	−120	− 24	− 13,824	
160	− 80	− 16	− 4,096	
170	0	0		
180	+ 90	+ 18	+ 5,832	
190	170	34	39,304	
200	300	60	216,000	
210	400	80	512,000	
220	530	106	1,191,016	
230	590	118	1,643,032	
240	670	134	2,406,104	
250	730	146	3,112,136	
260	850	170	4,913,000	
270	890	178	5,639,752	
280	805	161	4,173,281	
290	620	124	1,906,624	
300	330	66	287,496	
310	+100	+ 20	+ 8,000	
320	− 50	− 10	− 1,000	
330	− 80	− 16	− 4,096	
340	− 10	− 02	− 8	
350	+200	− 40	+ 64,000	Mean Cube
	Total Cubes.....		53,454,369	1,484,844

the cubes of the high-speed shaft torque is 1,484,844 and the root mean cube torque is:

$$\text{RMC average torque} = \sqrt[3]{1{,}484{,}844} = 114$$

The desired ratio is:

$$\frac{\text{Peak torque}}{\text{RMC average torque}} = \frac{178}{114} = 1.56$$

These two examples illustrate how these basic equations can be used to determine bearing application data in a general form. They can be applied to any problem where the characteristics of the load and speed are known or can be estimated with reasonable accuracy. The resulting factors are used in conventional bearing application formulas for selecting bearings for constant loads.

When applying anti-friction bearings to any type of machinery and under any type of loading conditions, it must be remembered that such practical considerations as shop errors, lubrication, and other factors may be of major importance in influencing the success or failure of the bearing application. For this reason the results of these computations should be considered with a number of other engineering and economic considerations such as: Life expectancy factors, criterions of satisfactory bearing life, manufacturing and maintenance factors. These may be broken down as follows:

A. Life expectancy considerations for Design.

1. Class of service—continuous or intermittent, industrial or domestic.

2. Manufacturing profit, guarantees, and maintenance or servicing policies of manufacturer.

3. Cost of bearings. Considered from the standpoint of:

(a) Percent of machine cost.

(b) buyers' criterions: specifications or competitive costs.

4. Bearing failure effects.

(a) Cost of replacement bearing.

(b) Cost of damage to other parts of machine or hazards to workmen.

(c) Cost of time loss.

(d) Cost of labor for dismantling and reassembling machine.

5. Design strength of equipment in which bearing is used.

B. Criterions of Bearing Life.

1. Average life as determined by testing many bearings.

2. Minimum life (B-10 life) is time of test when 10 percent of the bearings have failed. (Average life is approximately 5 times minimum life).

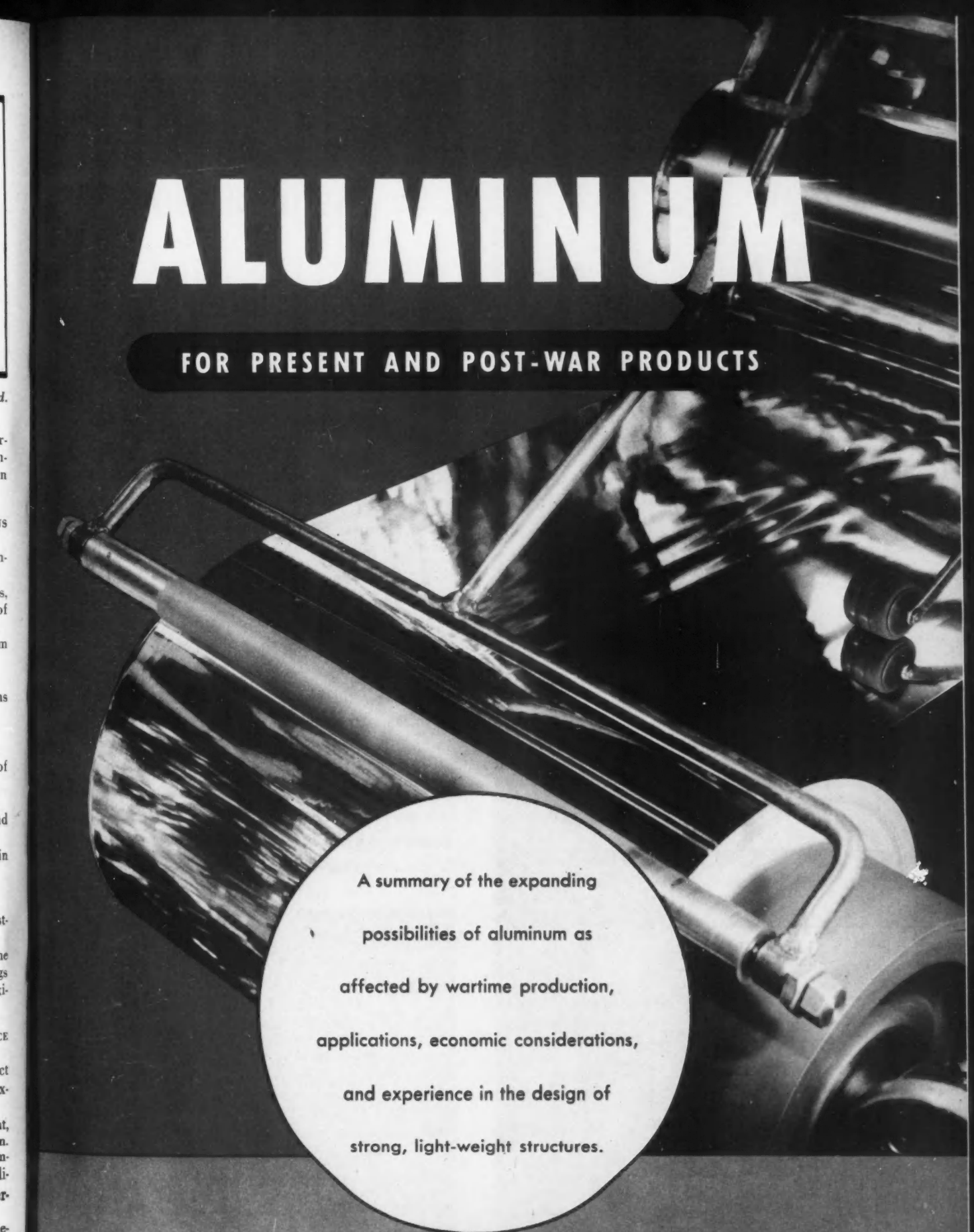
C. Manufacturing and Maintenance Factors.

1. Manufacturing errors—incorrect fits, misalignment, axial loading, and excessive preloading.

2. Lubrication—type, grade, amount, frequency, contamination, deterioration.

3. Operating conditions—loads, temperature, and speed. Operating conditions and lubrication are usually interdependent.

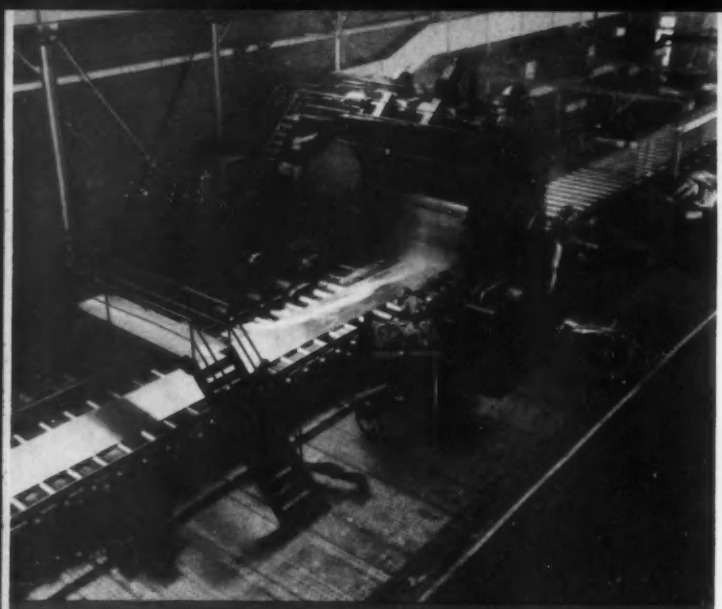
4. Misalignment resulting from mechanical deflections of shaft or housing in service. Housing distortion may be caused by thrust loads or too light construction. Misalignment puts the wrong kind of loading on bearings.



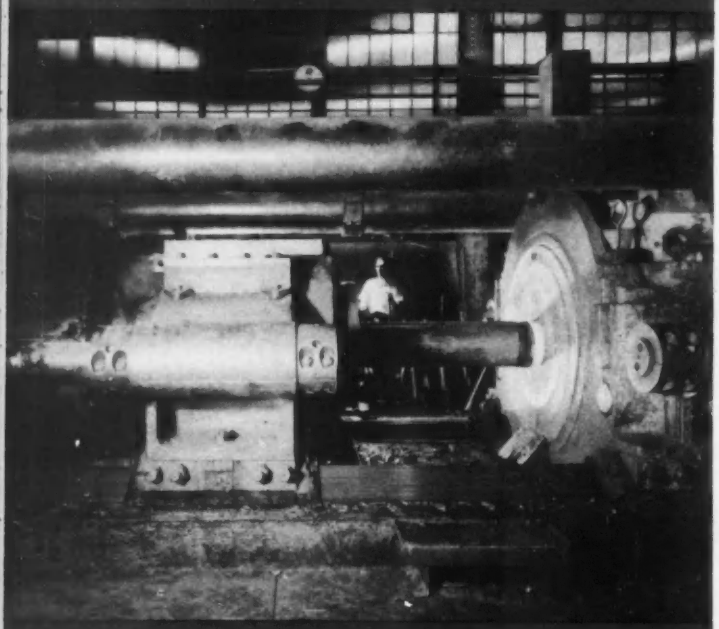
ALUMINUM

FOR PRESENT AND POST-WAR PRODUCTS

A summary of the expanding possibilities of aluminum as affected by wartime production, applications, economic considerations, and experience in the design of strong, light-weight structures.



Aluminum strip on runout table in hot mill. *Reynolds Metal Co.*



Extruded structural shapes and tubing are produced by this 4,000-ton hydraulic press, which forces an aluminum bloom through a die.
Aluminum Co. of America

Forming new R-301 alloy armor plate section for Douglas A-26 bomber.
Reynolds

DISTINGUISHING *Features* OF ALUMINUM

LIGHT WEIGHT — One-third that of steel.

STRENGTH — Although pure aluminum has only one-fourth the tensile strength of low carbon steel, about 15,000 lb. per sq. in., strengths of 60,000 to 70,000 lb. per sq. in. are available in heat-treated alloys, extruded, forged or rolled.

Although stiffness of an aluminum sheet is only one-third that of the steel sheet of equal thickness, it is nine times stiffer than a steel sheet of the same weight.

WORKABILITY is such that aluminum alloys are available in many semi-finished forms, it can have nearly all manufacturing operations and assembly methods used upon it, and almost unlimited types of finishes can be applied.

CORROSION RESISTANCE — Pure aluminum is highly resistant to atmospheric corrosion and many chemicals. Some of the alloys have lower resistance, but may be protected by pure aluminum cladding, or protected by other coatings or finishes.

CONDUCTIVITY — Thermal conductivity of pure aluminum is 3 to 4 times that of steel and iron. It has low emissivity and high reflectivity for radiant heat.

Electrical conductivity is about three-fifths that of copper, but higher than that of all other common metals except silver and gold. Aluminum is non-magnetic.

Thermal and electrical conductivity are reduced by alloying elements.

Non-sparking characteristics make aluminum safe in hazardous atmospheres.

Considerations IN DESIGN AND PRODUCTION

SEMI-FINISHED FORMS in which aluminum is available include:

Castings – sand mold, permanent mold, centrifuged, and die-castings.

Forgings – hammer, die, and press forgings.

Shapes – rolled and extruded.

Plate, sheet and foil.

Rods, bars and tubes.

Powders for compressed parts, metal spraying, paint, and pyrotechnics.

MANUFACTURING OPERATIONS that can be performed on aluminum include:

Metal-cutting operations – on lathes, planers, shapers, and milling machines. Threading, drilling, reaming, sawing, filing and grinding.

Stamping, forming, drawing, embossing, coining, and spinning.

Impact extrusion.

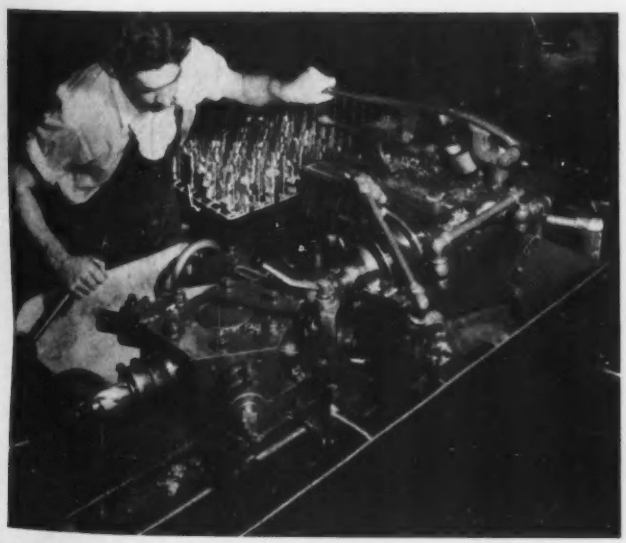
Techniques for best results differ from those used on steels although steel cutting tools can be used.

ASSEMBLY METHODS suitable for aluminum in any form include:

Mechanical fasteners of all types, and rivets.

Welding – gas torch, fusion welding, arc welding with metal or carbon electrodes, and atomic-hydrogen arcs, electric-resistance, and flash-welds.

Brazing – by torch, furnace, and dipping into molten flux.



Machining parts from aluminum bar on a hand screw machine. Alcoa

Adhesive bonding is a significant new development for sheet-metal assembly.

FINISHES that can be applied to aluminum include:

Mechanical finishes – polishing, scratch brushing, buffing, hammering, and sand-blasting.

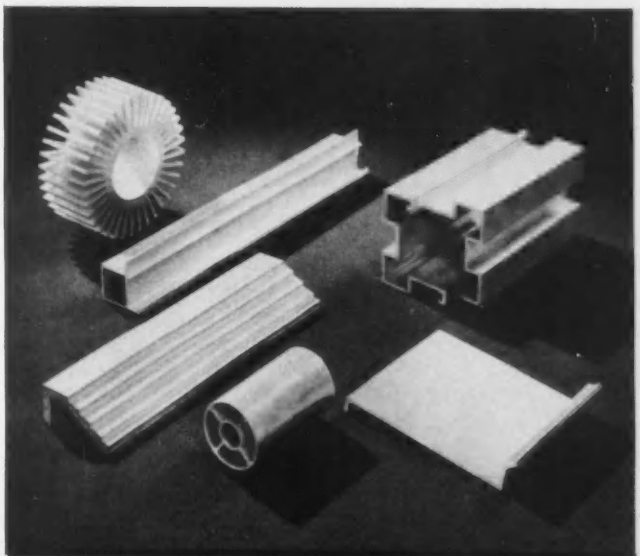
Chemical finishes – etching in various chemicals.

Anodic finishes – Oxide formed in various electrolytes.

Electroplating.

Metal spraying.

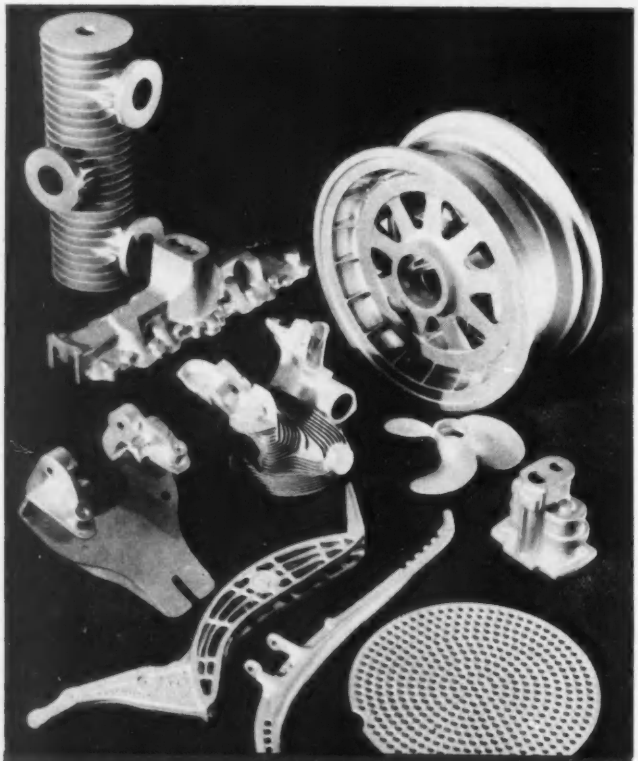
Paints, lacquers and enamels.



Various aluminum shapes that are produced by extrusion. Alcoa

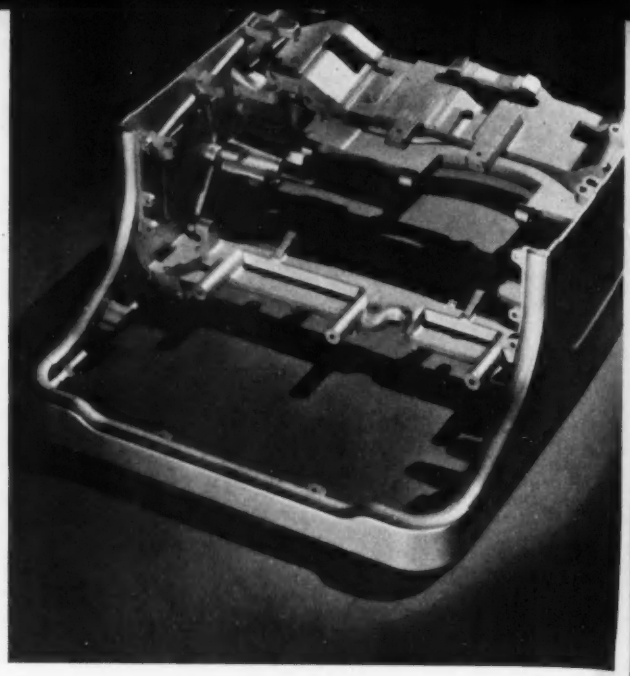
Typical prewar aluminum alloy castings made in permanent and semi-permanent molds. Alcoa

Castings



Aluminum sand castings having smooth, clean surfaces and good reproduction of detail. Alcoa

Removing a permanent mold casting from the mold. Alcoa



Die cast aluminum typewriter frame. Alcoa

SAND-CASTINGS as large as 7,400 lb. and 3 x 3 x 17 ft. have been produced. Size is practically unlimited. Unusual and intricate designs are produced with fine detail and good finish. Chills are being used to produce locally harder, smoother and denser surfaces.

PERMANENT-MOLD CASTINGS have higher mechanical properties, better surfaces, closer dimensional tolerances, and less finish allowance than sand castings. Rapid solidification in the mold produces higher mechanical properties than when the same alloy is cast in sand molds. These castings are particularly suitable for mass production. Semi-permanent mold-castings are made with sand cores. Such castings have had much development and improvement in the past two years, particularly affecting sand cores.

Molds for permanent-mold castings tend to be higher in cost than patterns for the same sand-casting and major design changes are not so readily made.

HEAT-TREATABLE CASTING alloys are used for probably more than 90 percent of wartime uses, more than 97 percent for aircraft castings, because of high strengths and other desirable characteristics.

NON-HEAT TREATABLE ALLOYS are used when the higher properties of heat-treated alloys are not needed or the castings are too large for treating furnaces.

DIE-CASTINGS — Because of accurate detail and smooth surfaces, machining, fabricating and finishing costs are reduced. High and low temperature properties are good. Several alloys are used. Casting temperatures are high.

CASTING ALLOYS

Sand-Mold Castings

ALCOA NO.	SALIENT CHARACTERISTICS	APPLICATIONS
43*	Good foundry characteristics, weldability, good corrosion resistance, pressure tight.	Leakproof castings such as for sewage disposal plants, pipe fittings.
47	Good foundry characteristics, better mechanical properties than No. 43.	Intricate castings.
108	Good foundry characteristics, pressure tightness.	Manifolds, valves, intricate castings requiring pressure tightness.
112	Widely used general casting alloy, good casting and machining properties.	General, crankcases, oilpans, cylinder heads, differential carriers, automotive parts.
122†	Hardness, wear resistance, elevated temperature service.	Automotive-engine pistons, camshaft bearings, valve tappet guides.
142*†	Elevated temperature strength, good bearing properties.	Pistons and air-cooled cylinder heads.
172	Excellent casting properties, small solidification shrinkage.	Match plates, metal patterns.
195†	Combined strength and shock resistance.	General structural castings.
212	General-purpose alloy, better foundry properties than No. 112.	General-purpose castings.
214	Combines good mechanical properties with high resistance to salt water.	Carburetor cases, machine parts.
B214	Better foundry properties, lower mechanical properties than 214. Excellent corrosion resistance.	Pipe fittings for marine and general use.
220†	Highest strength sand-casting alloy. High corrosion resistance except in acid solutions. Special foundry technique required.	Aircraft fittings, railroad car parts, heavy-duty castings, power shovel dipper parts, marine applications.
A334	Better tensile properties than 108, 112 and 212.	General purpose alloy, air-brake parts.
355†	Good foundry properties, corrosion resistance.	Cylinder heads, crankcases.
A355†	Modification of 355 with better strength at elevated temperatures.	Same as 355 but for higher temperatures.
356†	Good foundry properties, weldability, pressure tightness, corrosion resistance.	High-strength, pressure-tight castings of intricate shape.
645	Good mechanical properties, low resistance to corrosion.	Machine parts for normal temperatures and non-corrosive conditions.

Permanent-Mold Castings

ALCOA NO.	SALIENT CHARACTERISTICS	APPLICATIONS
A108	Especially suited for intricate castings.	General-purpose castings of intricate design.
B113	Good foundry properties, good machining properties.	Machine parts, general-purpose castings.
C113†	Modified B113 with better pressure tightness.	Automotive-engine cylinder heads, general-purpose castings.
A132†	Low thermal expansion, high temperature strength.	Pistons for internal-combustion engines.
138	Excellent hardness, retained at high temperature.	Brake drums, pistons.
B195†	Modified 195.	General structural castings.
A214	Modified 214.	Marine fittings and hardware.

* Both for sand- and permanent-mold castings. † Heat-treatable alloys.

Forgings

Hammer forged aluminum alloy crankcase section being removed from the die. Alcoa

Typical hammer forgings. Alcoa

FORGINGS are stronger and sounder than castings. Several alloys with ultimate strength ranging from 36,000 to 70,000 lb. per sq. in. are forged. Forgings are less resistant to creep above 500 deg. F. than castings. Most used alloys are Nos. 14S, 17S, and 25S-T. Alloy R-303 shows interesting possibilities.

HAMMER FORGINGS include beams with spans up to 20 ft. long made with flat dies.

Typical die-forgings are airplane propellers, aircraft fittings, connecting rods, locomotive parts and frames as much as 10 ft. long.

PRESS FORGINGS have closer dimensional tolerances and minimize machining. Typical applications are valve bodies, transmission clutches, brake pistons, universal joint parts, fittings, and housings.

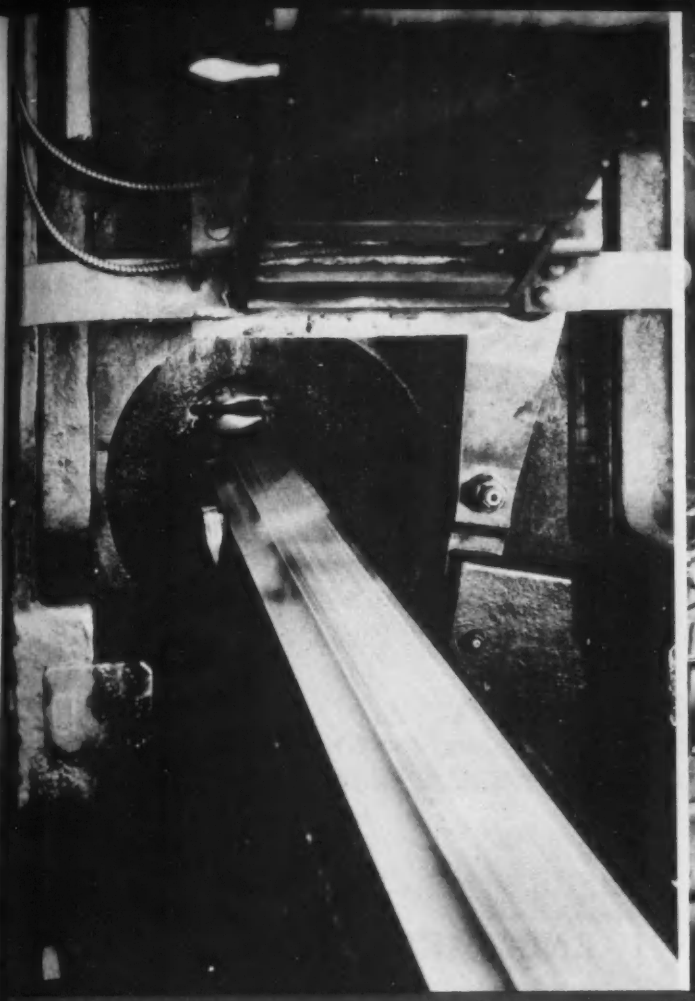
SIGNIFICANT TREND is toward larger die-forgings for aircraft structure. These make available single-piece intricate shapes for tying structures together, supplanting welded and riveted assemblies. Supercharger impellers and finned cylinder heads are being die-forged by means of new techniques.

Aircooled engine forged cylinder heads of the alloys generally used have about 25 percent higher heat conductivity than sand-cast cylinder heads of the alloys generally used. Fins in forged cylinder heads are machined but cast fins are not. By machining the fins, closer spacing and greater radiating area can be obtained.

FORGING ALLOYS

ALCOA NO.	SALIENT CHARACTERISTICS	APPLICATIONS
11S	Good machinability, good mechanical properties, comparatively low corrosion resistance.	Screw-machine products.
14S R303*	Highest strength and hardness (70,000 U.T.S.), artificially aged alloy.	Heavy-duty parts, power shovel bails, airplane fittings, structural members.
17S	Relatively high strength with fair workability and corrosion resistance.	Structural parts in construction and transportation equipment.
18S	Good strength at elevated temperature.	Aircraft engine pistons.
25S	Combines good forgability with 35,000 yield strength, 57,000 U.T.S. Comparatively low corrosion resistance.	Airplane propellers.
32S	Low coefficient of thermal expansion.	Pistons.
A51S	Excellent forgability, 47,000 U.T. strength, corrosion resistance.	Intricate machine and automotive parts.
53S	Excellent corrosion resistance, lowest strength (39,000 U.T.S.) and good workability.	Structures subject to corrosion; naval, architectural and industrial.
70S	Good mechanical properties, excellent forgability.	Structural applications in architectural and construction fields.

* Reynolds alloy



Extruded beam leaving the die in a hydraulic press. Alcoa

An aluminum sheet more than a city block long is rolled from one large billet. Alcoa

Sheet, Plate, Rod, Bar, Wire, Tube, Rolled and Extruded Shapes

VARIETY — More commercial wrought forms are available in aluminum alloys than in any other metal. A wide range of strengths and mechanical properties are available for fabrication of parts meeting many different needs.

SHEET AND PLATE are available in several alloys. Thickness range is 0.006 to 0.25 in. for sheet; up to 3 in. for plate. Standard width range is 12 to 48 in., but up to 102 in. sheet is available in 30-ft. length in two alloys. Plate 2 in. thick, 113 in. wide, 9.4 ft. long, can be obtained in the same alloys.

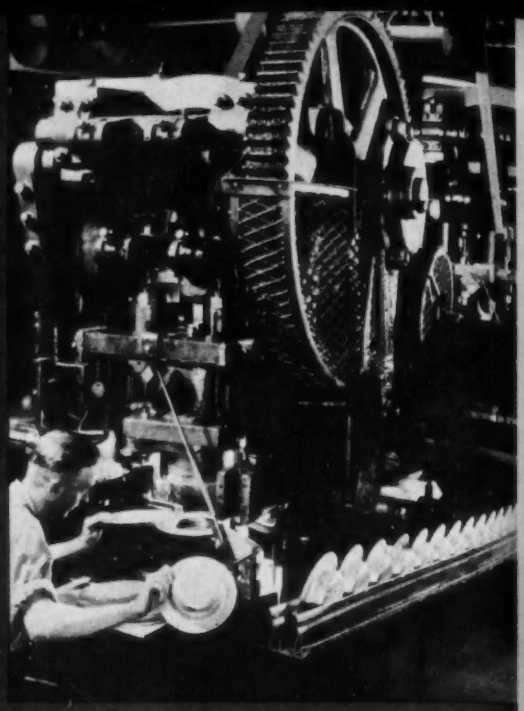
ROD, BAR AND WIRE are available in round, hexagon, and octagon shapes in several alloys, in squares and rectangles in all alloys, and in a variety of sizes.

ROUND TUBING, practically all seamless, can be obtained in a half dozen alloys, more than 60 wall thicknesses ranging from 0.01 to 0.5 in., and more than 450 standard sizes ranging from ⅛ to 11 in. O.D. Other shapes are also available.

ROLLED SHAPES, which include angles, I-beams, channels, H-beams, Tees, Zees, bulb angles, and wing channels, are made in large variety for structural applications.

EXTRUDED SHAPES of unlimited variety, including tubing, without the shape limitations of rolling, simplify design of aircraft and other structural members by eliminating "building up." Billets from 4 to 20 in. in dia. are handled in extrusion presses.

A giant clamp holds a sheet of aluminum in place while an air operated ram shapes it to fit the tail cone of a Republic P-47 fighter plane. *Westinghouse*



Initial drawing operation on circular aluminum alloy blanks. *Alcoa*

Fabricating Operations { FORMING, SPINNING, AND IMPACT EXTRUSION

WORKABILITY of commercially pure aluminum is among the best of all metals. Alloys are less ductile and workable. Pure aluminum can be taken through successive drawing operations without intermediate annealing. Aluminum-manganese alloy, 3S, is only slightly less easily formed. Hardenable alloys are generally started in soft temper. Both 17S and 24S, common airplane materials, can be formed considerably in heat-treated temper, usually before age-hardening takes place. Alloys 53S and 61S are formed readily, the latter taking more deformation than the former. Heat-treatable alloys have better forming properties at about 400 deg. F. but it is not standard practice in forming operations.

DEEP-DRAWN SHAPES are generally made from non-heat-treatable 2S, 3S, and 52S, and heat-treatable alloys 53S and 61S. Severity of draw determines temper to use. Drawn shells are usually round or rectangular but odd shapes are not uncommon. Since greatest metal flow is at corners, careful part design is required as well as careful die design. The strong alloys, such as 24S and R301, also undergo severe forming for aircraft parts.

SPUN SHAPES are used when quantity requirements are relatively low and tool cost must be low, for large circular parts, and when design is not suitable for deep drawing. Reasonably close dimensional accuracy and uniform size and appearance are obtained.

Non-heat-treatable alloys or pure aluminum are usually used. Aluminum-manganese alloy is often used because its strength is greater than pure aluminum, but it requires intermediate annealing on deep spinning, and more breakdown operations.

SHAPE FORMING, EMBOSSING, COINING AND STAMPING are less severe operations in which the uniformity of sheet thickness is negligibly affected. These operations are performed at relatively high speed, being completed usually in one strike of a single-action press. Roller dies can be used for stamping. Malleability and ductility are controlling factors.

IMPACT EXTRUSIONS are made by forcing a slug of aluminum to flow between side walls of a punch and die, and to take the shape of the clearance. Varying wall thickness, projections, bosses, stems, fillets, shoulders, flanges, longitudinal ribs and other details are made integral with the part. Close tolerances, smooth surfaces, uniformity, good mechanical properties, and low cost are reported. Sizes up to 6 in. dia. and 12 in. long are produced.

Machine spinning a large aluminum container. *Alcoa*

Semi-coining operation on an aluminum alloy tray is a combination of embossing and coining. *Alcoa*

Miscellaneous group of impact extrusions, pressing, and Hooker tubing. *Alcoa*

Impact extrusion press with rectangular aluminum can. *Alcoa*

Assembly Methods

WELDING

Commercially pure aluminum is most readily welded and manganese-aluminum, 3S, is nearly as easy to weld. Higher tensile strength alloys are more difficult to join by fusion welding but resistance welding properties of 52S are satisfactory as are 24S and 3S. Heat-treatable and non-heat-treatable wrought aluminum alloys and mold-castings are welded with equal ease but die-castings are difficult to weld.

GAS WELDING processes all give equal weld qualities and are suitable for butt and miter joints on any thickness of material. Oxyhydrogen and oxyacetylene flames are preferred for fastest work.

ARC WELDING by metal arc, carbon arc, and atomic hydrogen arc are all used on aluminum alloys.

Advantage of metal arc: Concentrated heat zone prevents excessive expansion and lessens distortion.

Joint preparation is simpler and welding rate faster.

Sealed joints in ¼-in. to ⅛-in. material are more difficult than by gas welding. No butt-welds are practical for material thinner than ⅛ inch.

Carbon-arc welding enables as sound welds as torch with much less distortion. Both manual and automatic welding are satisfactory. Thicknesses of 1/16 to ⅜ in. are welded manually.

Atomic hydrogen welding combines some of the flexibility of gas welding with concentrated heated zone of metallic and carbon-arc welding; decreases difficulty in welding 52S and similar alloys.

ELECTRIC RESISTANCE WELDING by spot or projections, seam or line, and butt or flash are applicable to aluminum alloys. Electronic welding control has greatly improved spot and seam welding of thin sheet.

Flash welding produces joints of equal or greater strength than fusion welding. Dissimilar alloys can be joined or aluminum alloys can be joined to other metals. Miter joints with angles from 60 to 180 deg. can be made

Torch welding a steam-jacketed kettle. *Alcoa*

Spot welding a baffle plate to sidewall of a gasoline tank. *Alcoa*

by flash welding. Production work is usually required for economy in application of flash welding.

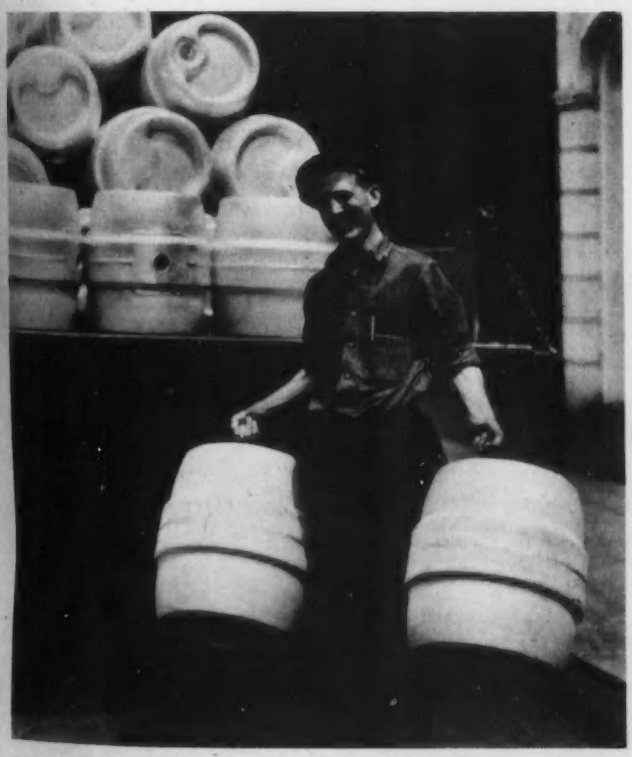
BRAZING costs are generally less than welding, joints are neater and require less finishing, and thinner parts can be joined. Lap joints are generally used with brazing. The only wrought non-heat-treatable aluminum that can be brazed satisfactorily are 2S and 3S, which are annealed by the brazing operation. The only heat-treatable alloys that can be brazed are 53S and 61S. Filler materials are aluminum alloys of lower melting point.

Strength of torch-brazed parts is approximately the same as gas-welded assemblies. Corrosion resistance is comparable to welded joints.

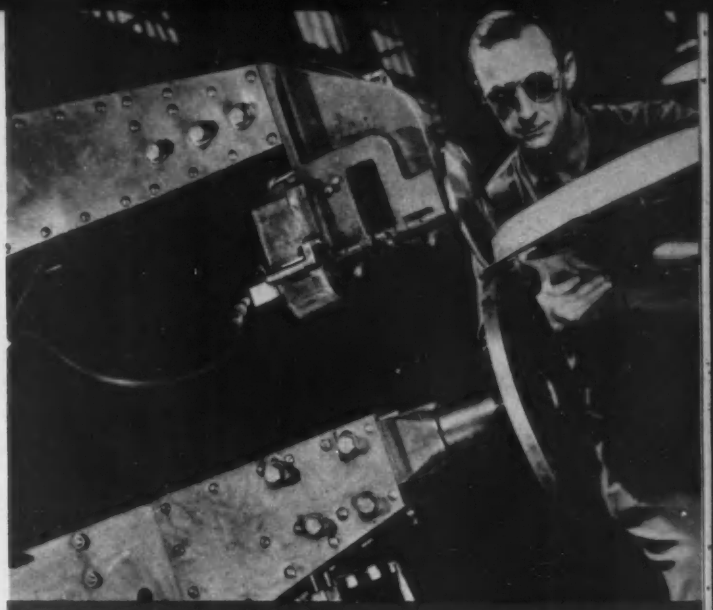
Furnace-brazed parts should be between 0.5 and 0.006 in. in thickness, and all joints on a given part should be nearly the same thickness.

DIP BRAZING is lowest in cost and has a short cycle of operation. Joints can be made in material as thin as 0.008 in. or possibly less. Commercial experience was limited before the war but possible applications are finned tubing, radiators, and assemblies that permit drainage of molten flux so that no corrosion is caused by it.

Brazing of castings has been done satisfactorily in some instances but is not fully developed nor are results uniformly satisfactory.

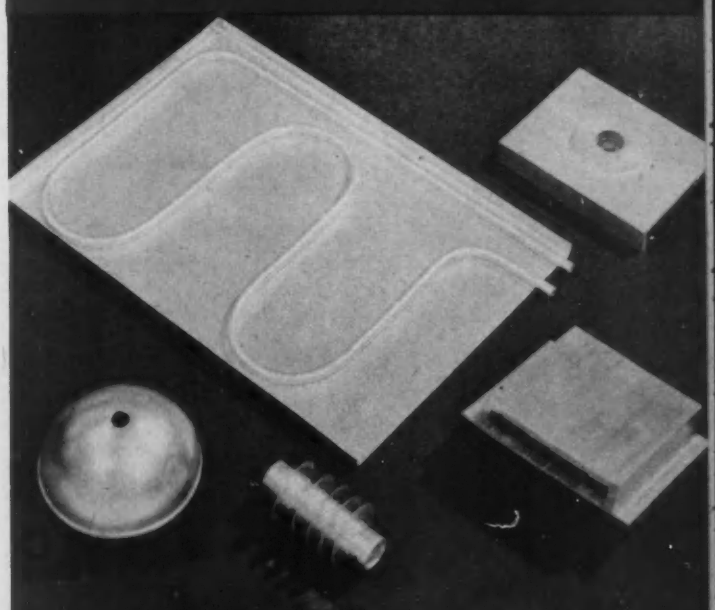


Beer barrels are fabricated by welding together deep-pressed stampings. *Alcoa*

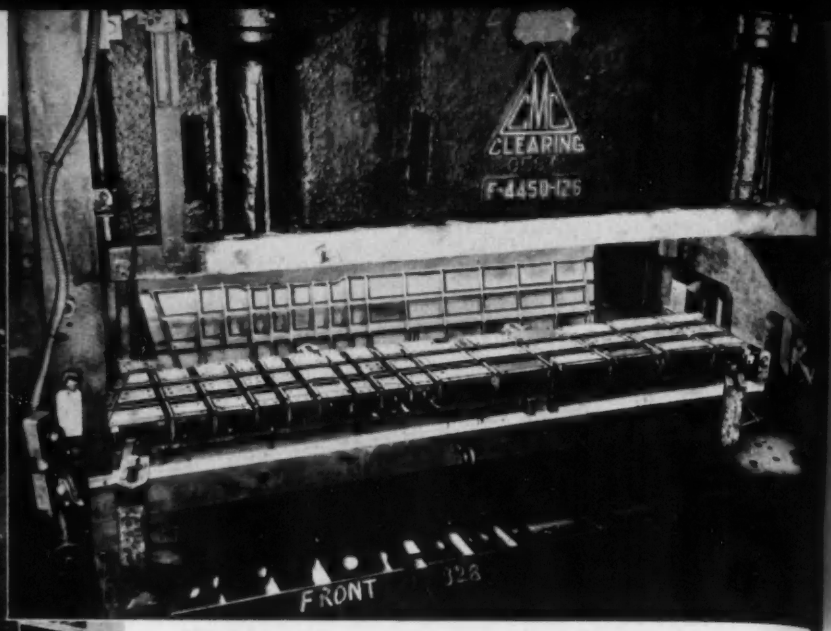


Seam welding an aircraft assembly made of Alclad sheet and other aluminum parts. Spring fasteners position the parts temporarily. Alcoa

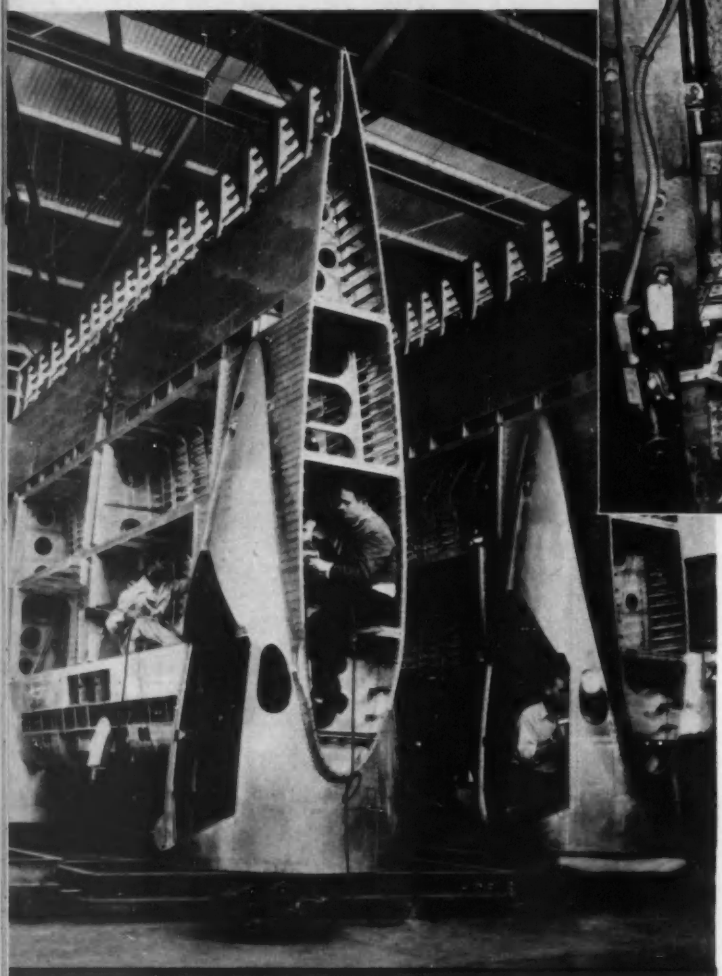
Furnace brazing aluminum gasoline tanks for outboard motors. Alcoa



Brazed joints are sometimes intricate and require delicate joining operations. They require less finishing than welded joints. Alcoa



Cyclewelding by means of adhesive joins grid-like rib assembly with skin of airplane wing flap. Segmented pressure pads enable proper distribution of pressure while at the curing temperature. Chrysler



Aluminum wing sections of riveted construction for a heavy bomber. Alcoa

Aluminum rivets being driven with a pneumatic hammer. Alcoa

Assembly Methods

RIVETING is the most commonly used method for joining aluminum alloys, particularly structural alloys that depend upon heat-treatment for their mechanical properties. Aluminum or steel rivets can be used, the latter only where protection against corrosion is used. Various head shapes are available in aluminum rivets and certain sizes may have shank ends chamfered.

Usually rivets are used either in single or double shear, but occasionally in triple and quadruple shear. With adequate edge distance, ultimate bearing strength in aluminum alloys in contact with driven rivets is about 1.8 times nominal tensile strength of the metal.

Joint design should avoid tension loads in rivets. Rivets having about the same properties as the material into which they are driven are generally preferred. Anodic coated rivets and rivets with burnished heads are also available.

ADHESIVE BONDING, a new joining process with new thermosetting plastic adhesives, is particularly advantageous for lightweight construction. Joint strengths even greater than with rivets or spot welding have been obtained in joining sheet. In attaching thin sheet aluminum to heavy structural supports danger of burning the sheet during welding is avoided. In some instances production rates in aircraft work have been greatly increased and cost greatly reduced. The method is used also in joining aluminum to other materials, such as wood, plastics, glass, see PRODUCT ENGINEERING, Jan. 1944, pages 1 to 5 and p. 32.

Machine and Cutting Operations

While machinability varies among aluminum alloys, all are machinable on all machine cutting tools. Commonly used tools for cutting steel will often perform satisfactorily but best results are obtained by following recommended procedures and techniques, often using specially designed tools and cutting compounds. Tools frequently resemble those used in cutting hard woods.

High speeds and fine to medium feeds are generally used. Light weight makes low inertia forces in machining operations in which the work moves.

Continuous and plentiful use of lubricant is advised. High thermal expansion means that if excessive overheating occurs during machining of cast or forged parts, warping and distortion may occur.

Finish allowance for sand castings should be ample but little or no machine finishing is required for permanent-mold castings, forgings, or other wrought products.

Most readily machined alloys include:

Casting alloys, non-heat-treated

173 C113 645 B113

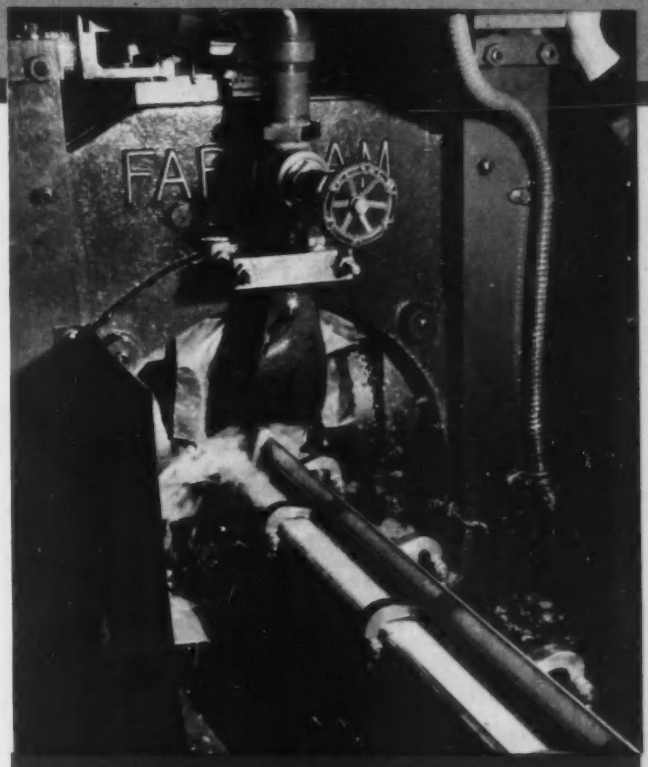
Casting alloys, heat-treated

220 (not aged) 122

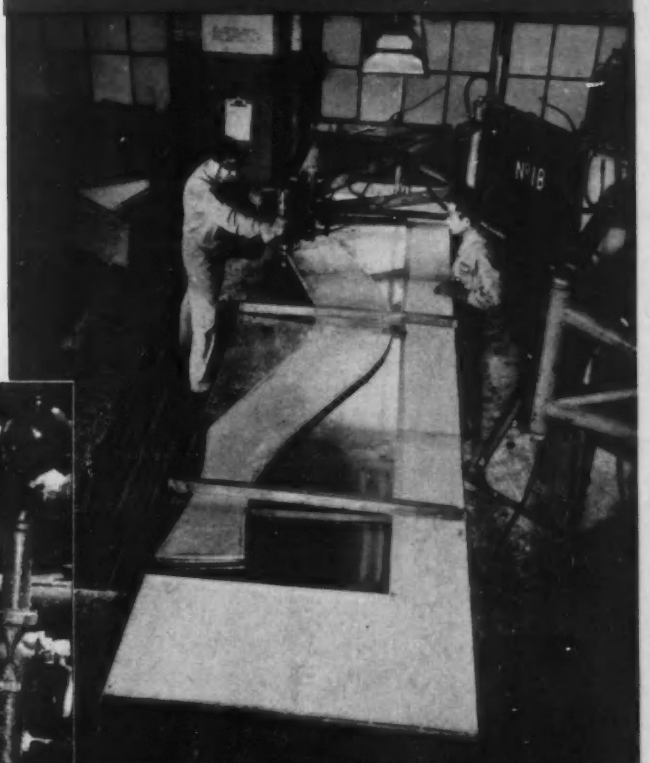
Wrought alloys, heat-treated

11S-T3 and R-317 – developed for free-cutting screw-machine work.

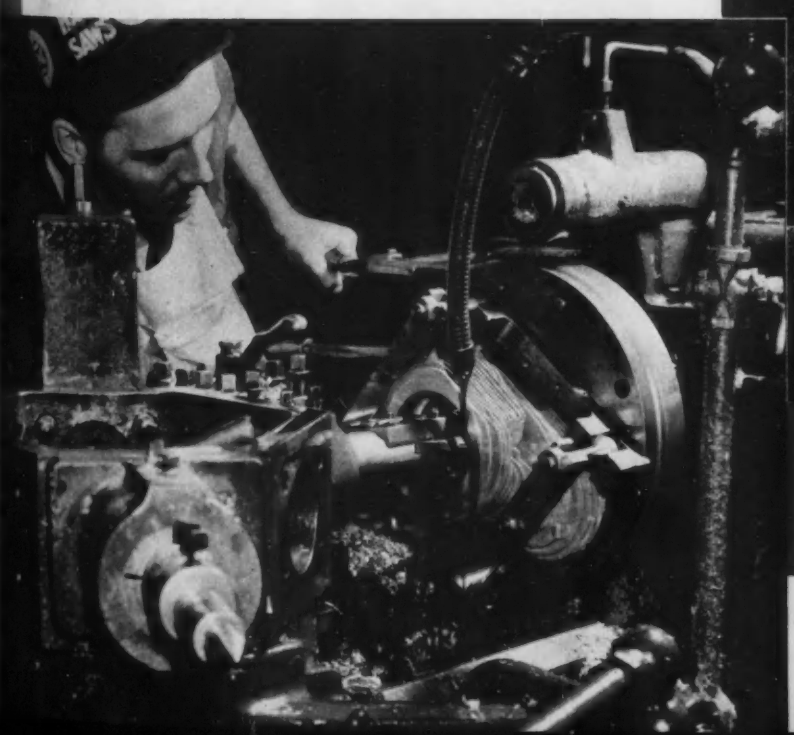
17S-T and 24S-T – widely used for automatic screw-machine stock.



Contour milling of cap strips for aircraft wing spars by means of template controlling height of cutters.



Routing out an aluminum part for a Navy fighter plane. *Reynolds*



Boring, chamfering, facing and contour turning the cylinder head for a Ranger aircooled engine.

Finishes

MECHANICAL FINISHES range from a matte produced by sand blast to a high luster by buffing and polishing. Aluminum alloys can also be given high light, scratch-brush, satin, swirl, hand-hammered, fluted or burnished finishes. Grinding removes irregularities or scratches.

CHEMICAL TREATMENTS produce finishes that combine corrosion protection with decorative value. They are low in cost but not resistant to abrasion.

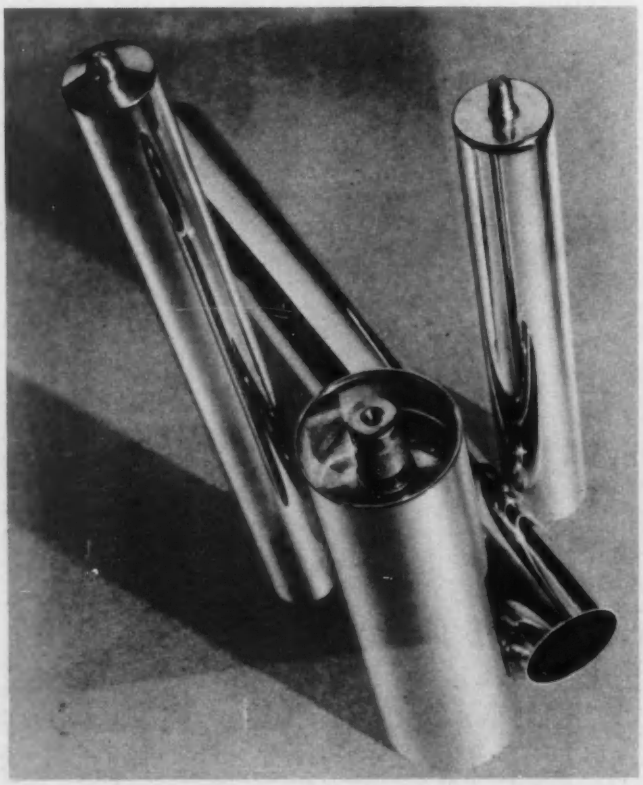
Frosted finish is silvery in appearance, like finely etched glass, and is usually protected by an anodic treatment in an electrolyte. Refrigerator trays and small intricately shaped products are finished in this manner. Etching is used to produce designs and in making name plates, signs, instrument dials, and the like. Diffuse reflector finish is another etching process.

A series of chemical treatments having protective value and for paint base have been developed recently. Principal features are low cost, minimum of equipment, but less resistance to corrosion and abrasion than coatings produced electrochemically. Generally bluish-gray, they may be colorless.

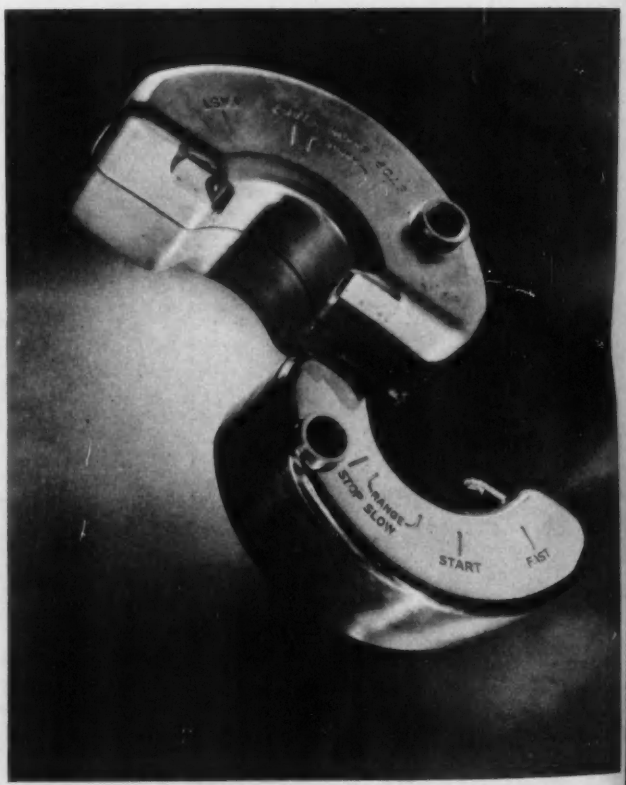
ELECTROLYTIC OXIDE FINISHES rank high in appearance, corrosion resistance, durability, and dielectric strength. A variety of colors are produced. The best of these methods produces a hard corundum-like oxide coating integral with the surface of the metal, which has high resistance to abrasion. Automobile pistons, cafeteria trays, are typical applications. Several sealing processes give these coatings high corrosion resistance and stain-proofness. Special electrolytic treatment produces reflection factors comparable with silvered glass.

ELECTROPLATING is applied chiefly for appearance and resistance to wear. Some of the most desirable metal platings are susceptible to electrolytic corrosion.

Common plating metals are nickel, chromium, oxidized



Extruded containers and collapsible tubes with high polish finish.
Alcoa



Outboard motor gasoline tanks before and after polishing. Braze line is ground off.
Alcoa

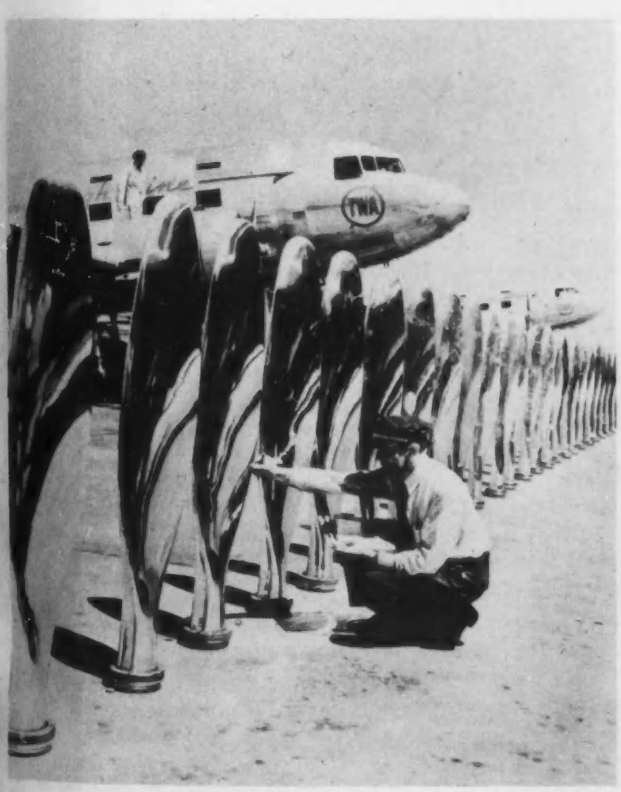
copper, brass, silver, zinc and cadmium. Chromium is applied directly and has several desirable qualities.

Colored or oxidized finishes can be applied on these deposits by the usual procedures.

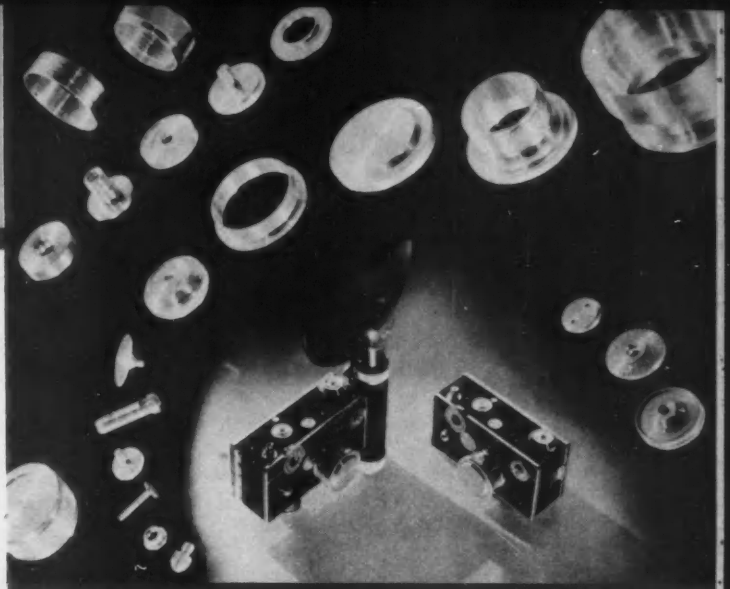
Aluminum cladding is produced by bonding a layer of high purity aluminum or aluminum alloy to the surface of a base of aluminum or aluminum alloy. Pure aluminum cladding gives increased corrosion resistance. Aluminum alloy cladding offers strength and wear resistance. Significant improvements have been made recently in clad aluminum sheet for formed parts.

PAINT AND LACQUER are often the most economical decorative finishes for aluminum. Some of these finishes give high corrosion protection.

All common methods of application are employed. Vitreous enamels of low melting point can be applied to aluminum but most of them are not resistant to slow attack of water.



Line-up of aluminum propeller blades inspected for use on TWA planes. *Alcoa*



Screw machine products for cameras are made of 11S-T3 alloy. *Alcoa*

Phenol-formaldehyde resin coated bucket and spinning spool. Forged bucket before machining is shown at left. *Alcoa*

Aluminum crankcases for Wright aircraft engines are sprayed with zinc chromate and two finishing coats of gray enamel.

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ASSOCIATIONS

ALUMINUM ASSOCIATION — An organization of producers, refiners, and fabricators of aluminum products. It is concerned with such matters as information service, market research, and standardization. Address: 420 Lexington Ave., New York.

ALUMINUM RESEARCH INSTITUTE — An organization of manufacturers of scrap or secondary aluminum and its alloys cooperating in problems of the industry, including information service, industrial research, market research, and standardization. Address: 308 W. Washington St., Chicago.

Deflections and Chatter In Machine Tools

GEORGE E. HIEBER
Design Department, Landis Machine Company, Inc.

Bending and torsional deflections in machine tools and the importance of calculating their accumulated effects as a procedure in design for the purpose of reducing vibrations or chatter and improving machine tool performance. Fundamental principles are reviewed and applied to a few typical designs of bed, headstock and gearbox.

IN MANY types of machinery if the parts are strong enough to withstand the applied loads they are satisfactory. Bending, yielding and deflection of parts can be tolerated as long as the part does not break. In some machines, it is not even important that parts return to their original shape or position after bending. But in a machine tool, the purpose of which is to hold a tool in relation to the work within close limits of a geometrical path, any spring, give, or deflection must be held to a minimum. As a result, machine tool parts are proportioned much larger than would be required if the parts only had to resist breaking.

In years of experience, the author has met machine tool designers and draftsmen in many plants and has learned that the majority never check a gear shaft for beam deflection to determine how many thousandths of an inch the gears might separate under load, nor do these men ever check a shaft for torsional deflection to learn how much the shaft will twist when under load. Yet, these designers will carefully consider and calculate antifriction bearing loads, gear strengths, strength of keys and screws.

After these designers were impressed with the importance of considering the effects of deflection, they could and did do it. Prior to using the simple algebraic formulas for beam and torsional deflections, the procedure was to use a rule of thumb, based on competitors' designs and practical experience. The trouble with the old alibi that what looks right must be right, is that some men have a queer sense of what looks right. Imagine a modern airplane engine being designed by rule of thumb or by the criterion of looking right.

Since all forces cause elastic deflections in proportion to the intensity of the forces, it is readily seen that a machine tool structure will vibrate in time and intensity with the applied forces. If the distance the structure can deflect is held to a low enough value any vibratory chatter also will be low. If elastic deflections are reduced enough the mass of the parts and their vibration dampening properties may absorb the chatter entirely.

Over the course of years, machine tools have been made increasingly heavier to secure stiffness or rigidity. It has been mostly a hit and miss process with usually only one weak spot redesigned at a time. This evolution by irregular improvement can be traced by looking over old literature such as catalogs, books, and technical magazines.

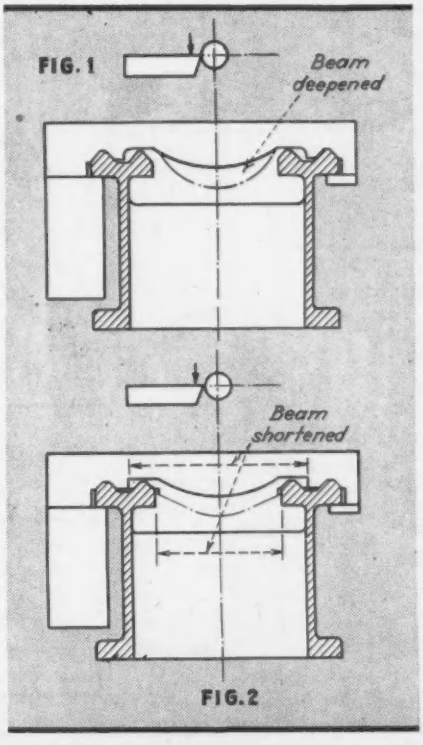

Fig. 1—Carriage bridge of lathe was stiffened by increasing the depth of section. Fig. 2—Further stiffening was obtained by adding bearings to ride on inside vees, with resultant shortening of the beam.

Consider the developments in lathe design. It seems that one manufacturer claimed that his lathe bed was heavier than competitors' lathe beds and therefore he had eliminated chatter and deflection. Much thought and time was immediately given to lathe beds. All the other parts were left as flimsy as before. Finally, somebody realized that other things could prevent a tool point from maintaining a stiff relationship to the work and he investigated carriages.

Immediately the carriage bridge from front vee to rear vee was deepened as indicated in Fig. 1. Eventually the beam formed by the carriage bridge was shortened by taking auxiliary bearings on the inside vees, as shown in Fig. 2. Finally, head stocks (cone pulley type) were redesigned, the front and back bearings which rested on the vees were tied together by bringing the side walls up or putting a tie across the top, thus increasing the stiffness of each bearing. The compound rest was stiffened, and the tailstock and the spindle were increased in diameter.

Some few manufacturers made a number or all of these improvements at one time. But not one considered the problem as a whole by investigating the actual deflection of each part, nor determined in advance how much deflection could be tolerated in a given part under load.

During the period of design development, gear drives supplanted belt drives and high-speed steel supplanted carbon steel. Also, more and more designers became aware of the need for stiffness in machine tools.

Since the total deflection is the sum of the deflections of all the parts in the connected structure, stiffening up one or a few parts will not give the minimum deflection that could be obtained by stiffening all the parts. Yet many designers will investigate the stationary parts of a machine tool for deflection

and totally ignore the revolving parts.

The first things a lathe hand learns is that the more opportunity a tool has to deflect the more chatter there will be as shown in Fig. 3. Also, that he cannot take a heavy cut at the tailstock end of a long, small diameter shaft such as is shown in Fig. 4, because it winds up and chatters. The same effect is obtained with a short, large diameter, rigid piece of work being turned on a lathe with a springy light carriage. The work and

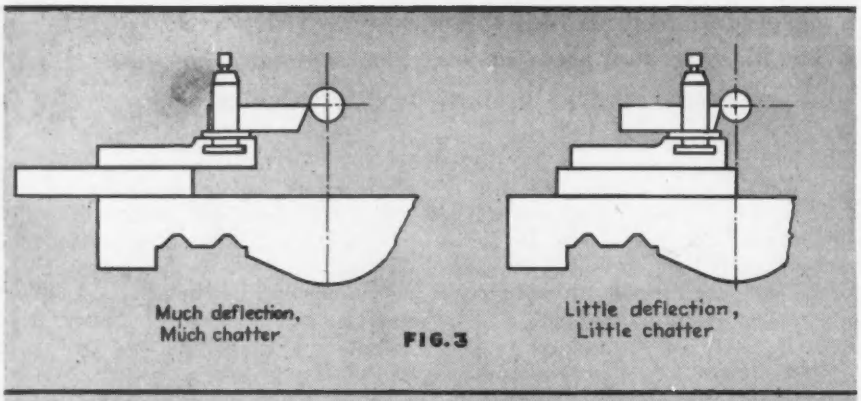

FIG. 3

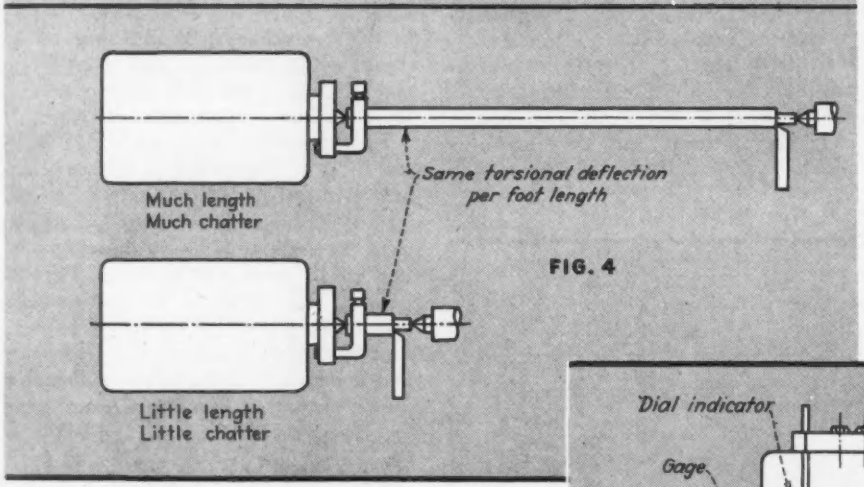

FIG. 4

Fig. 3—The more opportunity a tool has to deflect the more chatter there will be. Fig. 4—Torsional deflection and chatter are subject to the same laws that govern linear deflection effects.

the tool are pushed together. If either the work, the tool or any parts behind them can yield, then there will be deflections and the troubles that accompany it. Therefore, not only should the stationary parts be checked for deflection, but also all the rotary parts, from the spindle nose to the motor armature, should be checked for rotary or torsional deflection.

A simple test can be made easily to locate the weak spots in a machine tool. Lock the motive power source, in this example the motor armature, and arrange a hydraulic jack and a dial indicator as shown in Fig. 5. Then apply a very light load to take up all back lash, after which set the dial indicator to zero. It is then an easy matter to take a direct reading of the torsional deflection in thousandths of an inch at various loads. From a series of readings and by means of Hook's Law the deflection or spring between tool and work, at any given cutting load on any diameter, can be calculated. The indicator as shown in Fig. 5 is indicating the torsional deflection of the spindle in relation to the headstock. It does not make any difference how much the bed, carriage, or other parts bend; their deflections will not affect the indicator.

If the indicator is also arranged in different settings to show the individual deflections of carriage, bed, or other parts under various loads it will be at once apparent that most of the spring occurs because of lack of torsional rigidity. Too many machine tools of recent design have this weakness.

A hypothetical headstock is shown in Fig. 6 which has the gears so poorly arranged, with shafts so long and small in diameter, that the wind-up is as bad as if a cut was being taken at the end of a long small diameter shaft. The effect is the same, the only difference is that the wind-up is inside the headstock instead of outside. For the sake of simplicity Fig. 6 shows only the pairs of sliding gears in use. Other combinations of paired gears might not be as bad since the gears would be so mounted that the shaft lengths would be shorter. Casual inspection of some gear drives shows that the gears are so arranged that when shifted to the slowest speed, and consequently under conditions of maximum torque, the greatest lengths of shafts will be in use.

Bending Deflections

Shafts should also be checked for bending stiffness. In Fig. 7(*A*) a pair of gears are shown in a normal unloaded position. Fig. 7(*B*) shows the positions

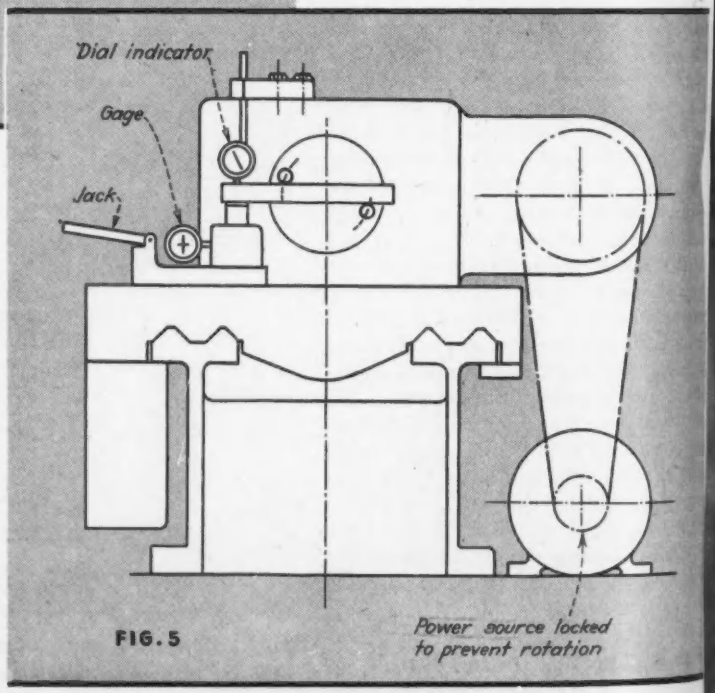

FIG. 5

Fig. 5—Arrangement of jack and dial indicator in making test to locate weak spots in a machine tool. Deflections are noted for loads on jack.

the gears take under load. Notice that in Fig. 7(*B*) the shafts wind-up as shown at *X* and *Y* and also spring apart. The rotary motion of the input shaft causes a springing apart of the shafts because of the pressure angle of the gear teeth. This adds to the torsional wind-up because the output shaft does not move while the shafts are springing apart, although the input shaft does. Both torsional deflection and rotary wind-up caused by bending deflection should be added together to get total wind-up. Wind-up caused by cantilever deflections of gear teeth is small enough to be ignored.

Flywheels Reduce Chatter

Hobbing machines because of the arrangement of parts sometimes have a long flexible drive system which could be a source of chatter, to reduce this effect a flywheel is added to the cutter arbor to store and release energy as near the cutter as possible. Such an arrangement cancels some of the effects of the flexible drive. If the flywheel is extremely heavy, the drive to it can be flexible and the cutter will still be driven at a fairly uniform speed. This principle is also used in punch presses, the motor drives a flywheel which stores energy over a comparatively long time and delivers it over a comparatively short time. Successive strokes of the punch press can be compared to successive chips taken by an interrupted tooth cutter such as a hob.

Changes in Planer Design

An interesting development of recent years has been the stiffening of planers. Planer drives with short shafts are torsionally stiff, but under the heavy loads of multiple tooling chatter may still develop. An analysis showed that on a double housing planer the side thrust caused by the two rail heads and one side head could spring the housings sideways. For years planer housings were made deep from front to back but not very wide from side to side, the proportions were about six to one. Unfortunately, the stiffness of a beam is directly proportional to its width, and even though the two housings mutually assisted each other by means of the upper tie or arch it was found necessary to widen the housings to obtain stiffness.

Modern planer design shows that improvement. Incidentally, the counterweights which used to hang outside the housings now hang inside, thus eliminating all danger to the operator in the event of the cable breaking. The rail has been deepened as a beam and the whole design improved in regard to deflections with the result that chatter has been immeasurably reduced. The

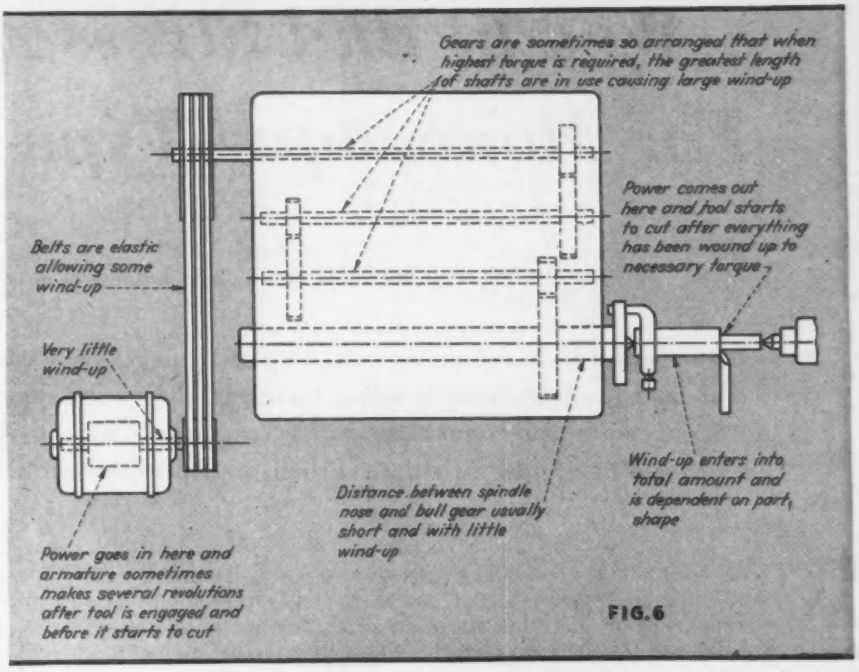
Gears are sometimes so arranged that when highest torque is required, the greatest length of shafts are in use causing large wind-up
Power comes out here and tool starts to cut after everything has been wound up to necessary torque
Belts are elastic allowing some wind-up
Very little wind-up
Wind-up enters into total amount and is dependent on part shape
Distance between spindle nose and bull gear usually short and with little wind-up
Power goes in here and armature sometimes makes several revolutions after tool is engaged and before it starts to cut
FIG.6

Fig. 6—Example of the effects of deflection in a poorly designed headstock.

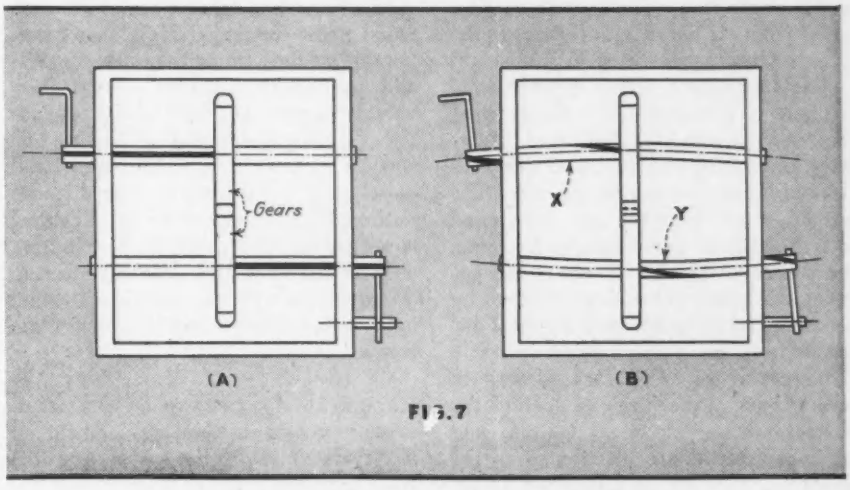

Fig. 7—Effects of combined torsional wind-up and beam deflection in a gear drive unit.

author has seen frog and switch planers take a cut with two tools at 16 ft. per min. and absorb 100 hp., or 50 hp. to the tool, with no chatter. Rigidity of the entire machine made it possible.

Objections might be made that the procedure of calculating deflections takes time and the results are not exact. The answer to that argument is: All the factors entering into such calculations may vary several percent but not enough to affect the answer more than a very small amount. All the designer wants to know is whether the machine springs 0.003 or 0.030 in. If he gets an answer of 0.003 in. he may be off a half a thousandth; but that is still better than not knowing approximately what is going to happen. As to the time taken for calculations, if the factors vary several percent, why use logarithms or extended calculations accurate to millionths of an inch? Use a slide rule and get the answer in several minutes.

Objections usually come from those who can readily work the problem when its importance is pointed out, but who at first do not realize the existence of the problem nor the usefulness of an approximate answer and so spend too much time carrying out the calculations with needless accuracy. Or else they will argue that design by experience is all right; they have designed successful machines before and they were all right. It is true that almost anyone can design a machine that will function after a fashion, but to be more than just a good machine a design must be the product of thought and experience.

Weight and Stress Analysis For Monocoque-Type Fuselage

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Procedure for distributing item weights to panel points to obtain loading analysis and for calculating bending moments, shears and stress at various sections in monocoque and semi-monocoque fuselages. Also a discussion of allowable stresses in circular or elliptical shells and practical arbitrary design procedures.

WHEN beginning the design of a monocoque-type fuselage, the outside contour and the approximate bulkhead locations are set. The horizontal locations of the bulkheads along the center line of the fuselage are used as panel points for the distribution of the weight items. The location of these panel points is found with respect to the same reference axes used in the weight and balance report. A structural drawing is made to a convenient scale showing the fuselage contour, bulkhead center lines, center line of thrust, and the vertical and horizontal references axes. The weights of all items are then distributed to the bulkhead panel points. Any item the center of gravity of which lies between two panel points is distributed inversely proportional to its horizontal distances from those panel points.

Weight items which are located in several bays of the fuselage, such as the control system, electrical system, and fuselage weight, are distributed to the panel points either by a detailed breakdown of the individual items according to weight and the location of their centers of gravity, or by logical estimates.

For the vertical location of the weight items, the panel points are considered to have no real vertical location with respect to the center line of thrust, but a vertical moment is identified with each panel point weight. Table I shows how to tabulate the summation of the vertical and horizontal moments of the individual weights applied to the various panel points designated in Fig. 1. The vertical moments are the individual panel point weights times their distance to the horizontal reference axis. Table I is not complete, it gives the distribution only as far as Station 2*U*. The horizontal moments are the individual panel point weights times their distance to the vertical reference axis.

METHOD OF ANALYSIS — SYMMETRICAL CONDITIONS. The bending moment at any cross-section of the fuselage results from both the vertical loads *V* and the drag loads *D*. The moment caused by *V*-loads is independent of the location of the neutral axes of the sections, while that caused by the *D*-loads depends directly on the neutral axis location. To simplify the analysis, a set of moments should be computed first that are independent of the neutral axis location. This method permits changes in the cross-sectional properties of the sections without requiring revisions in the loading analysis. These moments are computed about some horizontal reference line such as the weight and balance base line, the center line of thrust, or any other convenient line, parallel to the thrust line.

The moments are computed with one sign direction forward of the wing fittings and by the opposite sign direction aft of the wing fittings. Thus for any section forward of the wing fittings, the moment thus defined is equal to the summation of all the *V*-loads forward of the section multiplied by their respective horizontal arms to the section, plus all

Table I—Panel Point Distribution

No.	Item	Wt.	Vertical Arm	Vertical Moment	Horizontal Arm	Horizontal Moment	*P* 18.29 Wt.	*P* V. Mom.	*O* 55.00 Wt.	*O* V. Mom.	1 82.50 Wt.	1 V. Mom.	*2L* 102.40 Wt.	*2L* V. Mom.	*2U* 108.12 Wt.	*2U* V. Mom.
1	Wing Group	224.0	68.39	15,319.5	103.3	23,137.8							214.45	14,690		
2	Tail Group	38.6	94.9	3,661.5	245.2	9,464.7										
3	Fuselage and Cabin	185.8	81.5	15,142.7	126.6	23,416.3			13.0	1,017	22.0	1,874	55.0	3,964	18.0	1,714
4	Main Landing Gear	104.0	38.8	4,035.2	84.6	8,798.4					93.0	3,610	11.0	426		
5	Aux. Landing Gear	19.0	76.0	1,444.0	243.0	4,617.0										
6	Engine Section	36.5	75.7	2,763.2	39.0	1,423.6	14.8	1,120	21.7	1,642						
7	Power Plant Group	321.12	76.95	24,709.9	40.81	13,106.1	161.76	12,626	130.47	10,121	9.39	659	9.0	606		
8	Instruments	19.0	87.0	1,653.0	98.0	1,862.0			2.60	226	6.90	600			1.55	135
9	Surface Controls	50.0	70.0	3,500.0	115.0	5,750.0			6.0	420	11.0	770	12.00	840		
10	Furnishings	35.0	78.0	2,730.0	112.0	3,920.0			2.0	156	7.0	545	12.00	935		
11	Pilot	190.0	72.0	13,680.0	91.0	17,290.0					108.8	7,820	81.20	5,840		
12	Student	190.0	72.0	13,680.0	139.0	26,410.0										
13	Fuel	174.0	65.0	11,316.0	114.0	19,836.0							78.50	5,100		
14	Oil	12.0	78.0	336.0	35.0	420.0	6.53	510	5.47	436						
15	First Aid—Log Book	2.0	80.0	760.0	118.0	236.0							0.52	42		
16	Design Gross Wt.	1,601.02	71.65	114,241.0	99.8	158,887.9	183.09	14,256	181.24	14,008	258.09	15,878	413.67	32,443	19.55	1,849
17	Panel Point Moment		71.65	114,658.0	99.8	159,111.7	3,341.4		9,968.2		21,292.4		48,503.2		2,113.7	
18	Fuselage Group Gross Weight Less Wing Group, Fuel and Main land. Gear	1,098.22					188.01	14,256	181.24	14,008	165.09	12,268	169.72	12,221	19.55	1,849
						Station Spacing		36.75		27.50		19.90		5.72		15.33

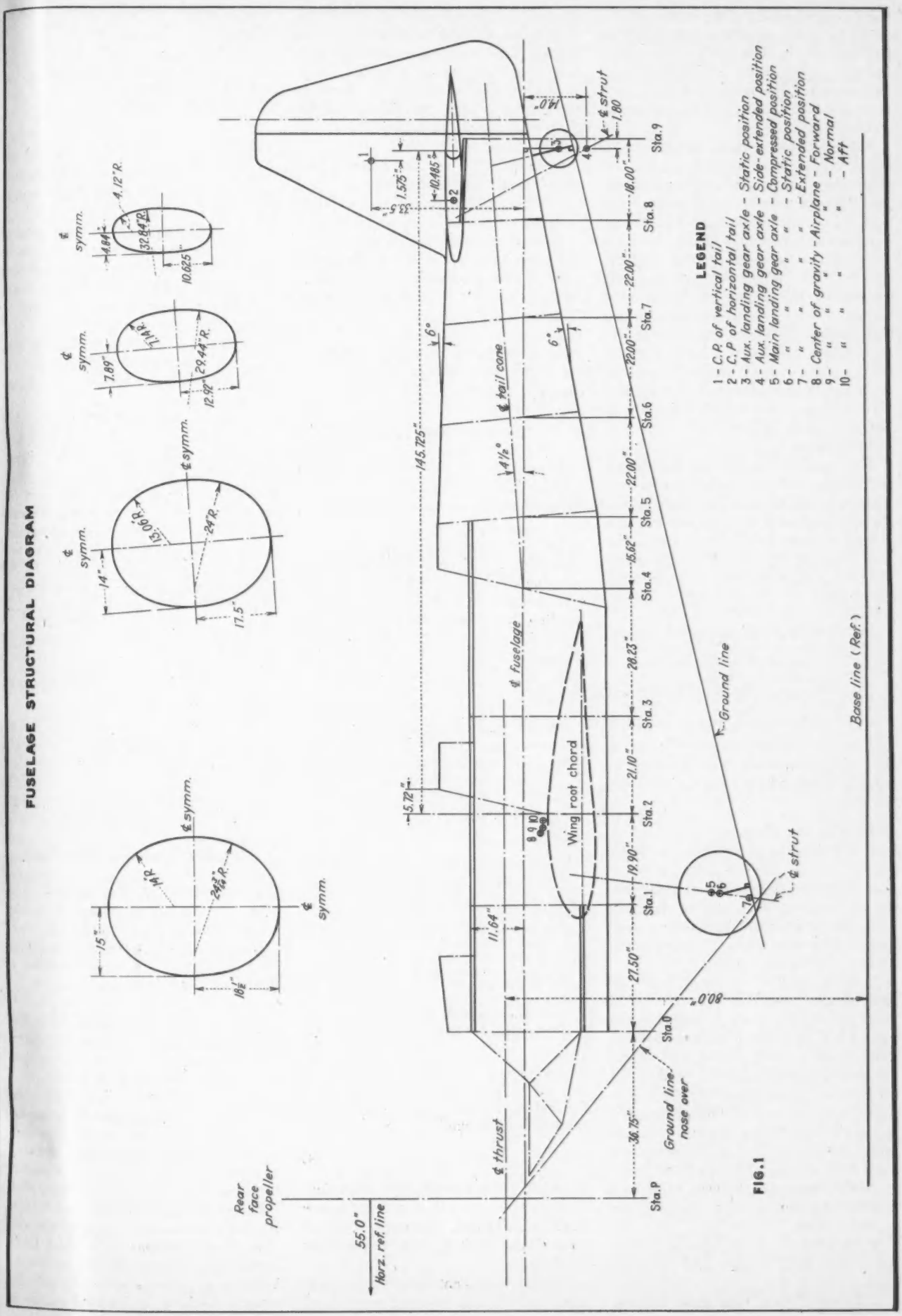
FUSELAGE STRUCTURAL DIAGRAM
LEGEND
1 - C.P. of vertical tail
2 - C.P. of horizontal tail
3 - Aux. landing gear axle - Static position
4 - Aux. landing gear axle - Side-extended position
5 - Main landing gear axle - Compressed position
6 - " " " " - Static position
7 - " " " " - Extended position
8 - Center of gravity - Airplane - Forward
9 - " " " " - Normal
10 - " " " " - Aft
Base line (Ref.)
Ground line
Wing root chord
℄ fuselage
℄ tail cone
℄ strut
℄ thrust
Ground line nose over
Rear face propeller
55.0" Horz. ref. line
Sta.P
Sta.0
Sta.1
Sta.2
Sta.3
Sta.4
Sta.5
Sta.6
Sta.7
Sta.8
Sta.9
145.725"
80.0"
℄ symm.

FIG. 1

the *D*-loads forward of the section multiplied by their respective vertical arms to the base line. For any sections aft of the wing fittings, the *V*- and *D*-loads used in computing the moment for any section are located aft of the section in question.

Evidently for a balanced system of loads, the moment obtained should be the same whether the computations are based on the loads forward or aft of the section. The computations should be carried out for partial loading systems that are not balanced by the wing reactions. The wing reactions are not needed for this procedure except as a means of checking the computations. For checking, the structure between the wing fitting stations must balance statically, using the loads at these stations from the fuselage forward of the front wing fittings, from the fuselage aft of the rear wing fittings, and from the wing reactions.

The moments as computed by this method are not truly bending moments. They are only apparent moments, since "bending moment means the moment about the neutral axis of a section." The true bending moment M is computed after the neutral axis of each section is determined.

Where
M = bending moment about neutral axis
M_b = moment about base line
P = axial load at station
y_o = distance from base line to neutral axis

$$M = M_b \pm P\,y_o \qquad (1)$$

The true shear between stations is obtained by dividing the increment in bending moment by the distance between the stations.

Outline of Procedure:

1. Distribution of weights to panel points.

2. Determination of shears and bending moments at each station resulting from the panel point loads, for a load factor of 1*g* (one times the acceleration of gravity) acting upward.

3. Determination of axial loads at each station resulting from the panel point loads, for a load factor of 1*g* acting aft, and the moments of these axial loads about the base line. These shears, bending moments, and axial loads are to be multiplied by the appropriate airplane load factors in the various design conditions, and to them are added the shears, bending moments and axial loads caused by the external loads, to obtain the resultant shear, axial load and bending moment about the base line at each station.

4. Tabulation of the design conditions, the load factors and external loads.

5. Calculations of total shear and moments about the base line for the critical conditions. Critical conditions can be quickly determined from the unit solution. (See "Truss-Type Fuselage Analysis With Graphical Solutions," PRODUCT ENGINEERING, page 182, March, 1944). Comments pertaining to non-critical conditions should be included.

6. Calculations of true bending moments about the neutral axes.

7. Plotting of shear and true bending moment curves for critical conditions.

Moments causing compression in the uppermost fibers, with the airplane in a normal flight position, are positive both forward and aft of the wing fittings. Thus an axial load above the base line and acting aft, if forward of the wing fittings, causes a positive moment; if aft of the wing fittings, the axial load causes a negative moment.

Stress Calculations

A pure monocoque is made up of formed sheet with no longitudinal stiffening elements except at discontinuities such as cut outs, and at points of application of large concentrated loads. Therefore, the shell is the main stress-carrying component, and the total cross-sectional area is considered effective in bending and shear. The conventional beam theory is used in calculating the stresses in the shell structure resulting from vertical and side bending loads.

Where
f = tensile or compressive stress in fiber at distance y from neutral axis
y = distance of fiber from neutral axis
M = bending moment
I_N = moment inertia of section about neutral axis

$$f = \frac{\pm M_y}{I_N} \qquad (2)$$

Longitudinal shear stresses f_s throughout the section are calculated by the conventional formula in which

f_s = unit shear stress
V = vertical shear
Q = static moment, about the neutral axis, of the area above the section investigated
t = shell thickness
b = twice the shell thickness = $2t$
I = moment of inertia of entire section

$$f_s = \frac{VQ}{bI} \qquad (3)$$

For elliptical sections in which a is the semi-major axis. Equation (3) when transformed becomes

$$f_s = \frac{V}{K_s\,a\,t} \qquad (4)$$

in which K_s is a coefficient dependent on the shape of the section. (Reference *N.A.C.A.-T.N.* 527, "Strength Tests of Thin-Walled Dural Cylinders of Elliptic Section).

Torsional moments impose uniform shear loads on the skin at any closed cross section of the shell structure, where

f_{st} = shear induced by torsion
T = applied torsional moment
A = inclosed area of section
t = skin thickness

$$f_{st} = T/2At$$

For open sections the torsional moments T impose equal and opposite shear loads on the sides of the section.

ALLOWABLE STRESSES. In the design of circular or elliptical shell sections, the allowable stress in the section resulting from pure bending alone, pure longitudinal shear, and pure torsion can be found from the test data of *N.A.C.A. Technical Notes* 523 and 527. The data of these references should be studied in detail before use is made of the design curves presented.

A large scattering of the test data prevents the empirical determination of accurate design curves. A few recent authors have recommended the use of conservative equations which are the lower limits of the test results. This approach is impracticable for final design where structural weight is a major consideration. It is more logical to use equations which represent the average of the test results, except at large values of the parameter R/t (R being the radius of curvature of the shell) where slight variations in the construction of the specimen causes a relatively large scatter of the test results.

The strength of a shell section subjected simultaneously to several types of loading can be best determined with the aid of utilization factors. This method of analysis is treated in *A.N.C.*5 "Strength of Aircraft Elements."

Semi-Monocoque Fuselage

LOADING ANALYSIS. The method of analysis for the shear, axial and bending loads throughout the structure is identical to that used for the pure monocoque-type fuselage. The same method of panel-point distribution is used.

STRESS CALCULATIONS. The analysis of a semi-monocoque fuselage varies from that for the pure monocoque fuselage only in the stress calculations. A semi-monocoque structure is one in which the thin-walled cell which forms the outer contour of the fuselage is supported by many longitudinal stiffeners and frames. The stiffeners are usually the main load carrying members, since the outer skin is so thin that it buckles in compression. By necessity the skin does carry the shear and torsion loads. In analyzing stressed-skin structures, use is made of a transformed or effective section in which the buckled portion of

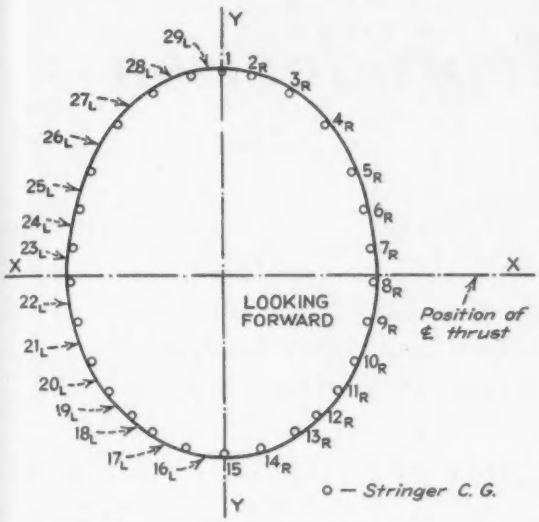

Fig. 2—Cross-section of stiffened thin-walled fuselage structure.

Table II—Section Properties—Lower Side in Compression

Element	Area	y	Ay	Ay^2
1	0.134	37.4	5.01	187.5
2L, 2R	0.268	36.3	9.73	354.5
3L, 3R	0.268	33.6	9.00	302.6
4L, 4R	0.268	30.0	8.04	241.2
5L, 5R	0.268	23.1	6.19	143.1
6L, 6R	0.268	16.0	4.29	68.6
7L, 7R	0.268	8.5	2.28	19.4
8L, 8R	0.328	−0.3	0	0
9L, 9R	0.328	−6.1	−1.99	12.2
10L, 10R	0.328	−12.2	−4.00	48.8
11L, 11R	0.328	−18.1	−5.94	107.5
12L, 12R	0.328	−23.4	−7.65	178.5
13L, 13R	0.328	−26.9	−8.81	237.0
14L, 14R	0.328	−28.6	−9.39	270.0
15	0.164	−29.7	−4.89	144.5
29L, 29R	0.384	37.5	14.40	540.0
28L, 28R	0.352	35.6	12.52	446.0
27L, 27R	0.352	32.2	11.33	365.0
26L, 27R	0.528	27.0	14.26	385.0
25L, 25R	0.512	20.0	10.24	205.0
24L, 24R	0.512	12.5	6.40	80.0
	6.842		+71.02	4,336.4

the skin is considered ineffective in compression. Only that portion of the skin which is immediately supported either by the rigid stiffeners or by its own curvature is considered effective in compression.

For preliminary calculations, the first step in the analysis is to assume a stiffener shape, area and spacing, and the skin gage. The section properties of the stiffener are computed and the allowable column stresses determined from actual column tests or empirical column curves based on the bulkhead spacing and the amount of end fixity. If the stiffener is considered acting at this stress, a certain effective width of skin can be assumed to be acting at the same stress. This effective width can be determined from

$$2w_e = 1.7\, t \sqrt{E'/f_m}$$

where $2w_e$ = effective width of skin acting with each stiffener
t = skin thickness
f_m = unit stress in stiffener
E' = tangent modulus of elasticity of skin material corresponding to the stress in the skin

On the basis of this effective area of skin acting with each stiffener, section properties of the cross section are determined. All the stiffeners and skin on the tension side can be considered as fully effective.

If the maximum tension or compression stresses in the outermost stiffeners from the neutral axis are found to be excessive or too low, the stiffener area or spacing will have to be changed and the section and stress recalculated to obtain the most efficient design.

To show how this procedure is applied, stresses will be determined for a stiffened thin-walled structure the cross section of which is shown in Fig. 2. The bending moment of this section will be taken as 3,000,000 in. lb., the allowable column stress of the stiffener is 35,000 lb. per sq. in. and the effective area of the 0.032 skin is 0.030 square inch.

In Table II are given the calculations for finding the effective neutral axis of the section. Term y is the distance of the center of area of the member from the XX axis in Fig. 2 and is used to calculate the moment of area, Ay, and the moment of inertia, Ay^2, of the members about the axis XX. In this design the summation of the moments of area is plus 71.02, which when divided by the sum of the areas gives the distance from the XX axis to the effective neutral axis, or

$$\bar{y} = \frac{71.02}{6.842} = 10.4 \text{ in. above } XX \text{ axis}$$

The moment of inertia of the section about the neutral axis is then

$$I_N = Ay^2 - A\bar{y}^2$$
$$= 4{,}336 - 6.842 \times (10.4)^2 = 3{,}596 \text{ in.}^4$$

The distance from the neutral axis to the outside fiber in compression is

$$29.7 + 10.4 = 40.1 \text{ in.}$$

therefore the fiber stress is

$$f_b = \frac{3{,}000{,}000 \times 40.1}{3{,}596} = 33{,}550 \text{ lb. per sq. in.}$$

With an allowable stress of 35,000 lb. per sq. in., a positive margin of safety is shown.

No completely rational procedure exists at the present time for the determination of stresses over the cross-section of a stiffened thin-walled shell or beam in bending, but the approximate procedure described appears to yield satisfactory results and is used in general practice. More exact calculations can be made at the stress analyst's discretion. For example the resistance of the skin between stiffeners in compression resulting from its radius of curvature may be considered. Also the effective area of skin acting with the stiffeners may be determined on the basis of the stress at each individual stiffener rather than that of the most highly stressed stiffener. Taking these points into consideration leads definitely to a more accurate analysis.

Longitudinal shear stresses throughout the section are calculated by the conventional formula

$$f_s = \frac{VQ}{bI}$$

where Q and I are values corresponding to the effective section. It should be kept in mind that high shear stresses in the skin induce axial and bending stresses on the stiffeners because of the buckling of the skin and the corresponding diagonal tension effects.

REFERENCES

N.A.C.A.—T.N. 523. Strength Tests of Thin-Walled Dural Cylinders in Combined Shear and Bending.

N.A.C.A.—T.R. 473. Strength Tests of Thin-Walled Dural Cylinders in Compression.

N.A.C.A.—T.R. 474. Stability of Thin-Walled Tubes in Torsion.

After-Glow Technique Of Template Reproduction

THOMAS MILES
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Consolidated Vultee Aircraft Corporation

There are now several template-reproduction methods that utilize the glow from phosphorescent materials that have been subjected to X-rays. The latest and best known of these methods are discussed and evaluated.

TO eliminate the slight background fog on prints made by the primary-exposure method, the after-glow method of reproducing templates was developed. In the former method the X-rays not absorbed by the fluorescent layer will expose the film and give a pearly-gray background to positive prints, particularly those given prolonged exposure. To eliminate this effect the method of making most exposures on sensitized material by after-glow was developed and North American Aviation, at Inglewood, Calif., was one of the first to install it.

Since the activation exposure of the layout to X-rays is much longer for after-glow than for primary-exposure, it was necessary to use an X-ray unit of higher energy output and mount it overhead in a lead-lined chamber. The 200- to 250-kv. peak X-ray unit is turned on and an activation of 5 to 10 min. is made at a distance of 14 ft. from the layout. The activated layout is then removed to a vacuum frame and an after-glow exposure of 5 to 10 min. made in vacuum contact with the sensitized material. The processing of the exposed sheet is the same as that described in PRODUCT ENGINEERING, Mar., 1944, p. 190, for the primary-exposure method.

A monotype camera has also been installed at North American to enlarge the scope of reproduction facilities, including the making of reduced-scale transparencies, the ability to make reproductions from layouts on material other than fluorescent lacquer and the making of shrink-template reproductions on fluorescent material for other divisions that have X-ray equipment but no camera.

To eliminate the intermediate step of making a metal negative, and to obtain reproductions of better line quality, North American has adopted the practice of spraying the fluorescent-lacquered sheet with a softer template-masking lacquer. The color of this masking lacquer is adjusted to ease the loftsman's eyes and is usually greenish grey. The lines are then scribed through the masking lacquer to the fluorescent layer, being careful not to scribe deeply enough to penetrate through the fluorescent layer to the metal. Choice of the proper masking lacquer will tend to prevent this.

Since the resultant reproductions by this method are posicons and the metal negative step has been eliminated, it is necessary to lay out the drawing opposite to established practice for left-hand layouts, and the lettering is done backward with the aid of a Wrico set. Lines may be changed by painting out the unwanted sections and rescribing after a short drying period. This painting can be done with a brush or, more easily, by an air brush.

This masking technique is most easily established in the lofting group or in the template department where the personnel is accustomed to scribing. Some difficulty may be found in introducing it in the experimental project room where the detailers have numerous changes to make and are accustomed to using pencils. The pencil drawing is more easily changed and has the advantage of being more like the customary pencil vellums. However, if scribing is used throughout the design system, this method will fit into the system at step (3) in the general schedule given in the first article (PRODUCT ENGINEERING, Jan., 1944, p. 57) of this series.

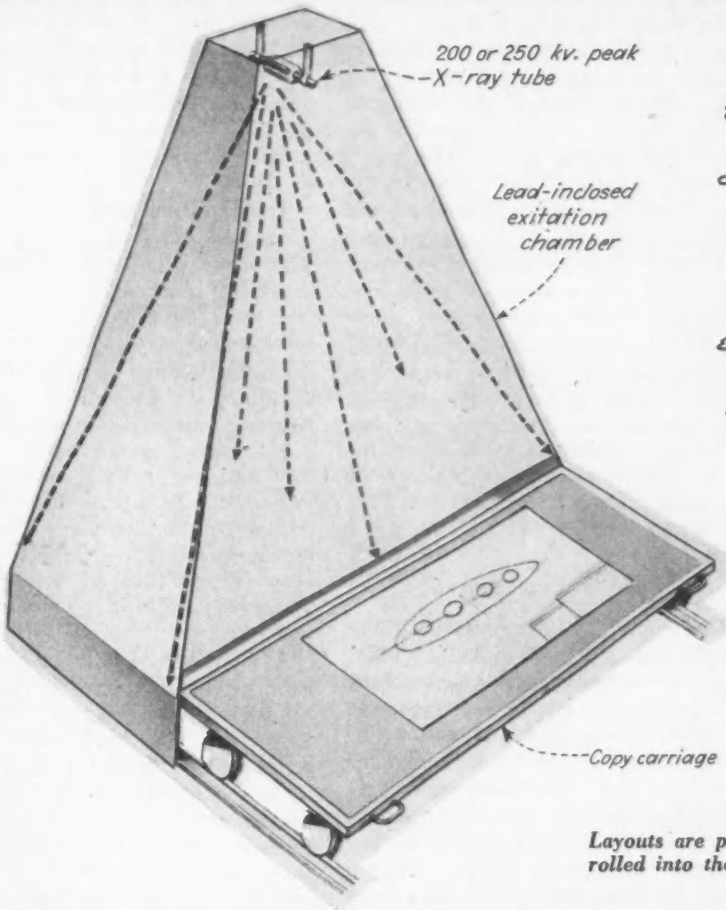
It would be difficult to attempt to lay down a number of sensitized sheets on the phosphorescent layout without considerable fogging before the vacuum can be applied. It is also evident that an unreasonable length of time would be involved to make several reproductions from one layout, exposing the small sheets one at a time for 5 min. Consequently, it is more advisable to confine the after-glow technique to the reproduction of large drawings requiring only two to five prints, and the making of metal negatives.

Another effect noticed by the Vultee Field laboratory is the excessive exposure required to produce good line density from this "hand-made negative." The increase is as much as ten times and seems to be a result of the separation of the phosphorescent or fluorescent layer from the sensitized material. Only a few thousandths separation will increase the exposure greatly as compared with the absolute contact of the pencil-line masking method. The same accuracy is held by this method as with all of the methods which involve a direct metal-to-metal contact.

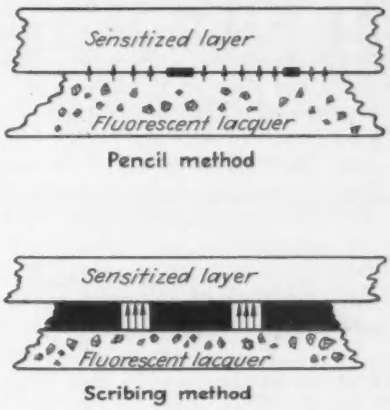
The making of transparencies, matching to a complete contour from either right- or left-hand reproductions and the variety of materials upon which reproductions can be made are the same with the after-glow as with the primary-exposure method.

Cost of the necessary equipment is about $14,000, excluding the darkroom and sensitizing equipment. By concentrating on large-size reproductions, it is possible to run between 1,500 and 2,500 sq, ft. per shift with a relatively small crew. This process has been applied at step (4) or step (11) in the general schedule given in the first article of this series.

Boeing Aircraft, at Seattle, previously had used the projection method of reproduction and decided to combine its advantages with the after-glow method. Glass negatives made with the camera from layouts on white lacquered metal were projected in the usual way onto sheets prepared as metal negative stock, with a sensitized film over fluorescent lacquer. Thus, when the single reproduction was checked for dimensions, any number of prints could be made by X-ray, eliminating considerable time in checking additional copies from the camera. Also, an increased-scale template for the plaster shop could be made



Layouts are placed on a carriage and rolled into the excitation chamber.



Absolute contact between surfaces is secured when pencil lines are drawn on the fluorescent-lacquered sheet, above, as compared to a separation of these surfaces when lines are scribed into a coating, below.

and any number of copies run at some later date without having to set up the projection system to the "shrink" scale. Reduced-scale reproductions for model work and reduced-scale transparencies for blue-printing can be made from fluorescent originals.

Phosphorescent Masking

Republic Aviation Corporation, Farmingdale, L. I., developed a method of reproducing templates, parts and other items with the aid of a phosphorescent paint. The original drawing is made on a sheet of metal sprayed with phosphorescent lacquer and overcoated with black masking lacquer. A scribe is used to remove the masking lacquer along the areas to be reproduced, care being taken not to scribe into the phosphorescent layer beneath. When the drawing is complete the exposed phosphorescent lacquer is uniformly activated with ordinary lighting or fluorescent lamps. The phosphorescence thus obtained is used to expose a photo-sensitized sheet of template material, the two sheets being placed in a vacuum frame to insure good contact. The exposed template sheet is now developed by customary photographic solutions. The print would be a posicon, black lines on a white background, but would read as a mirror image unless scribed in reverse.

To obtain left-hand and right-hand reproductions or to match either half of a contour to make a complete contour, the lines are scribed through a masking lacquer applied to thin plastic sheets. Either left- or right-hand reproductions can then be made by printing in a glass-topped vacuum frame to a photo-sensitized surface. Transparencies can also be made in this manner.

Dimensional stability of this process would be limited only by the thermal-expansion coefficient of the plastic used in the second method described. Reproductions can be made from a permanent loft layout floor with the aid of a portable light-tight box to protect the sensitized material from exposure to room lights. The maximum size that can be printed at one time seems to depend more on handling facilities than any other factor, with the possible exception of the sizes of plastic sheets available.

The necessary equipment for this process includes sensitizing equipment, glass-topped vacuum frame, processing equipment and darkroom facilities. This method would be instituted at step (3) or (4) of the general schedule.

Recently the Di-Noc Manufacturing Corporation introduced a method of reproduction using a light-activated phosphorescent paint which is sprayed on the master layout metal, sanded and the lines drawn with 6H pencils or ink. This is known as Lumi-Loft. Reproductions are made from the Lumi-Loft drawing by applying a stripping transfer material, Photo-Loft, to another sheet prepared with Lumi-Loft, activating the drawing to phosphorescence with a 2-min. exposure to a photoflood and placing the sensitized, but not phosphorescent, Photo-Loft sheet in contact with the activated drawing in a vacuum printing frame for 2 to 3 min. This produces a negative with phosphorescent material underneath.

After regular photographic processing the negative is activated with the photoflood, replaced in the vacuum frame with the sensitized material to be used as a positive reproduction and exposure and processing carried out as before. The Photo-Loft transfer material may be applied to almost any flat surface and is supplied in three speeds and contrasts for contact, projection or contact and projection.

Similar methods using phosphorescent materials have been tested in this labo-

ratory. All of the phosphors so far tested have been found quite susceptible to deterioration by contact with moisture and various oils in human perspiration, and tend to deteriorate beginning after several months and ranging to almost complete decomposition after two years. No tests have been run on Lumi-Loft, however. One other criticism was the fact that the phosphors have to be carefully protected from all light except red safelights for some time before sensitizing for negative stock. This is somewhat difficult to do in the present high-production era unless ample storage space is available.

Transparencies may be made by this method by the customary contact printing to the phosphorescence. There is evidently no restriction in size and the necessary equipment consists of an activation chamber, contact printing frame, processing tanks and a laminator similar to that required for the application of Eastman Linograph transfer paper (PRODUCT ENGINEERING, Jan., 1944, p. 57). This process would be introduced at step (3) of the general schedule.

Transphoto Process

Fleetwings Division of Kaiser Cargo, at Bristol, Pa., had occasion to reproduce a good many templates within a limited time. Since no reproduction process had been installed it was decided to take advantage of the small amount of equipment required, and consequent rapid installation time, of the Transphoto process. Reproduction work was started within four days.

In this method, the original drawings are scribed onto sheets of metal coated with zinc-chromate paint. A piece of Transphoto film is then immersed in a special solution and squeegeed in contact with the drawing for 5 min., removed and processed in a hypo solution, rinse water, bleach and transfer solution. By squeegeeing the wet film in contact with degreased Galvaneal or other materials sprayed with a special zinc-base paint, a positive print is obtained after several minutes of contact. One transfer can be made per film, the used film being stripped of emulsion and returned to the vendor for reclamation.

Accuracy of 0.015 in. over 10 ft. is assured with proper squeegee technique. If many duplications of the same drawing were to be made, this method would be quite expensive and time consuming, but when only one or two are required, it is very efficient. The maximum sizes of Transphoto film are not known to the writer. This process would probably be best suited to use at step (11) or (12) in the general schedule.

Reflectography

The Photoprint Corporation, of Los Angeles, has a method of making reflex negatives by contact and printing back to a positive on any desired sensitized material. This method is now in use by many aircraft companies but is limited at present to a 4x6-ft. maximum size.

The drawing to be reproduced is made with pencil lines on white lacquer. The negative is prepared by laminating a sheet of translucent-based, very high contrast reflex paper to a glass plate, or in some cases to a plastic sheet. When the cement is dry, the sensitized glass is placed, emulsion side up, in a glass-topped vacuum printing frame, the drawing to be reproduced is placed face down on the sensitized surface, a vacuum blanket is placed over the sandwich and the lights turned on for a few seconds. The light passes through the emulsion without giving it sufficient exposure to produce a strong latent image; but when 75 percent of the light is reflected from the white areas of the drawing and back into the emulsion the increased exposure makes possible development to a high density. The black pencil lines will not reflect enough of the light to increase materially the exposure already made by the passage of the light.

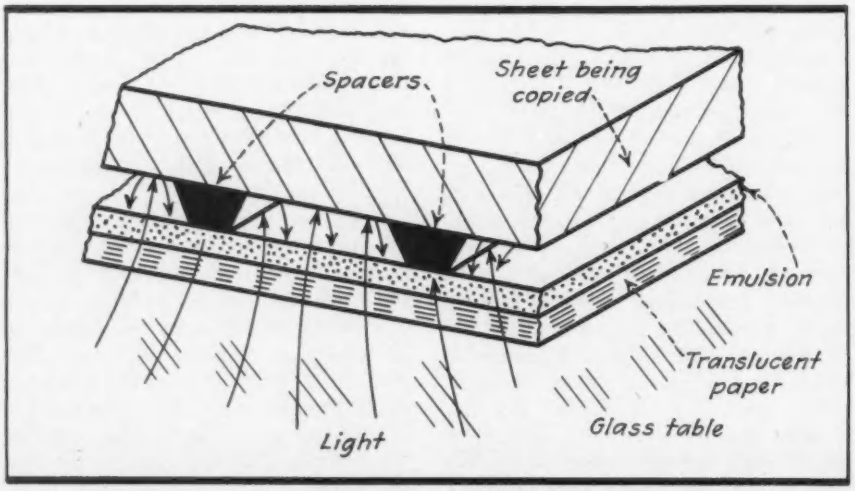
The developed negative is usually immersed for a few seconds in a reducing bath to clear the lines, then washed and dried. It is now ready to be placed again face up on the printer and by placing a sensitized sheet face down on it, covering with a vacuum blanket and exposing again to light, a positive is made by the customary transmission method.

The glass negative can be recovered for future use by dissolving the laminating cement in a tank of solvent and stripping off the translucent paper bearing the image. The sensitizing emulsion used for positives in the Photoprint process is applied with a silk screen and squeegee.

A moderate installation capable of handling 3x5-ft. negatives made from originals up to 5x12 ft. costs about $3,500 and consists chiefly of a silk-screen holder, drying racks, processing tanks, recovery tanks and a glass-topped contact printer slightly larger than 3x5 ft. surrounded by a table big enough to work any part of a 5x12-ft. drawing over the glassed area. The whole table area is covered by a rubber sheet that can be rolled across the drawing. By applying a vacuum from a small pump good contact between the negative and material being printed can be obtained.

The process holds lines with no appreciable widening. Negative right-hand prints can be made by printing the negative to a positive on another piece of negative stock and, after processing, printing the resultant transparent positive back to a negative, or right-hand, layout on any desired material. Working from these two transparent plates it is possible to print an entire contour from either half by placing registration points on the centerline of the original drawing and matching the two transparent plates by printing one half, locally developing the registration points, matching the second to these points and printing again. The same procedure followed by the projection method, (PRODUCT ENGINEERING, Feb., 1944, p. 130) in splicing very long images is recommended. Transparencies are made by using sensitized paper or vellum in place of sensitized metal. This method fits into the organization at step (3) of the general schedule.

EDITOR'S NOTE—Chemical and electrolytic methods for reproducing templates will be covered in the next, and final, installment.



Reflex printing involves passing light through the emulsion-coated paper to the sheet being copied and having part of the light reflected back to the emulsion.

INDUSTRY AND SOCIETIES

NEWS • READER LETTERS • MEETINGS

Twelfth Model Lightning Incorporates Many Improvements

IMPROVEMENT in various performance phases of the P-38 Lightning airplane are incorporated in a new model that has been rolling from the Lockheed Aircraft Corporation assembly lines for some time. This twelfth model, capable of carrying two 1,000-lb. bombs, packs the heaviest bomb load of any fighter-bomber. Major improvements in the new model, responsible for greatly expanded production by means of subcontracting, are:

Rate of climb increased 100 percent at altitudes over 30,000 ft., and materially increased at all altitudes.

Range increased 30 percent, permitting the Lightnings to accompany bombers on escort missions deeper into enemy territory.

Service ceiling increased to "well above 40,000 ft." with better performance all the way up.

Straightaway speed increased, depending on altitude.

Single-engine speed increased to over 300 m.p.h.

Combat maneuverability more than doubled by mechanical aids to the pilot, in the form of hydraulic aileron boosters combined with the old combat flap.

New unit power controls and automatic temperature controls that further help to simplify operation for the pilot.

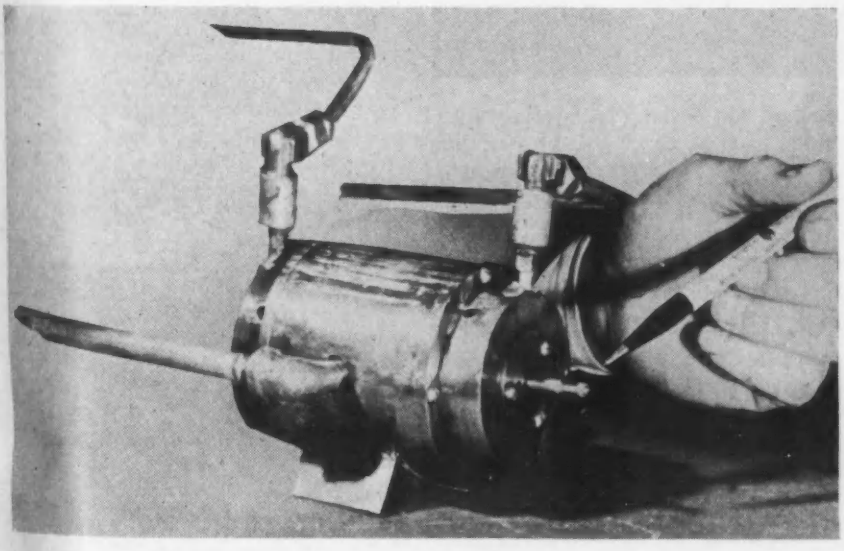
Installation of an improved turbo-supercharger and new intercooler installations, boosting the power of the twin Allison engines from 1,150 to 1,500 hp. each, which increases considerably the Lightning's superiority over Axis fighters. When the Hamp model of the Zero, for example, (PRODUCT ENGINEERING, Mar., 1944 p. 145) which weighs less than half the Lightning, is at top speed in level flight, the new P-38 can fly faster and climb more rapidly. The Hamp's rate of climb falls off at 15,000 ft. but the Lightning climbs with top efficiency to nearly twice that altitude.

On the score of versatility, the Lightning stands out in that it is used as a high-, low- and medium-altitude fighter, an interceptor, a bomber escort, for ground strafing, as a tank buster, dive bomber, skip bomber, night fighter, for smoke screening and as a glider tow. In its photographic version, it is the fastest photo-reconnaissance plane of the Army Air Forces.

Lightnings were the first fighter-type aircraft to fly the Atlantic, and by using dropable auxiliary fuel tanks they can fly any ocean.

Armament of the new P-38 remains the same as predecessors, consisting of one 20-mm. cannon and four .50-cal. machine guns, concentrated in the nose to give greater straight-ahead fire power over a longer range.

3-Hp. Motor Operates at 120,000 R.P.M.

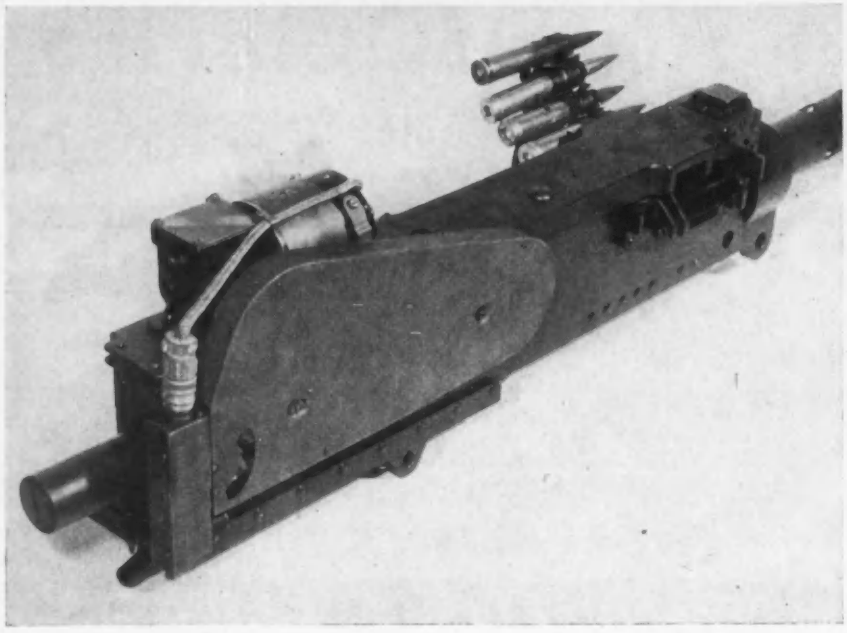


Operating at 120,000 r.p.m., this motor was developed by General Electric Company for application to internal grinding machines or small drill chucks. The motor is rated at 3 hp. and weighs 7 lb. With normal voltage applied at 2,000 cycles it reaches full speed in less than a second. The rotor is only slightly larger than a man's thumb. High-precision bearings with nearly perfect dynamic balance are required. A special oil-mist lubricated type of bearing is used. The amount of material in the motor is so small, with a consequent reduction in radiating surface, that water cooling ½ gal. per min., is utilized.

Two Plane Engines Made from Same Parts

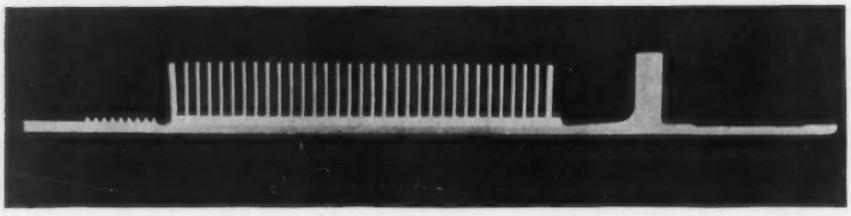
MANUFACTURE of a new 14-cylinder radial engine developing 1,200 hp. for use in high-priority cargo planes has been announced by the Buick Division of General Motors Corporation. The engine is a Pratt & Whitney twin-row Wasp type, comparable in most parts with the Pratt & Whitney R-1830-43 engine used in Liberator bombers. This makes possible the production of many parts and sub-assemblies for both engines on the same machines and assembly lines. Additional machines accommodate design changes.

Machine Gun Charger Cures Jamming



Mounted on a .50-cal. Browning aircraft machine gun, a charger developed by Eureka Vacuum Cleaner Company loads the first shell and clears jams and duds automatically by means of a specially developed electric control. A stoppage is cleared in less than 3 sec. and the gun is back in operation.

Aluminum Bonded Chemically to Steel



Improvement in the cooling efficiency of the cylinders and reduction in structural weight of air-cooled engines are advantages of the Al-Fin process, a method for chemically bonding aluminum to steel developed by Fairchild Engine & Airplane Corporation and now in use on 12-cylinder Ranger engines.

Discussions and Comments From Readers

SPACER RING MOUNTING ANGLE FOUND BY ANDERSON

Of the several solutions submitted to the problem presented by P. H. Winter in PRODUCT ENGINEERING for January, page 64, that given below is typical and concise. The problem involved finding the highest point on a spacer ring, and the angle at which to set a magnetic chuck upon which the ring would be mounted when grinding the ring to get the proper dimensions. The spacer has an outside diameter of 10 in. Also, the spacer had to be 0.0048 in. thicker at B than at A, 0.0050 in. thicker at C than at A, and 0.0002 in. thicker at D than at A. These points, shown on the diagram, are the same as those given in the problem as originally published.

To the Editor:

Concerning Mr. P. H. Winter's problem of the non-parallel spacer ring, we may obviously consider the ring to be a solid disk. From the definition of the problem, let

t_A = thickness of disk at A.
$t_B = (t_A + 0.0048)$
$t_C = (t_A + 0.0050)$
$t_D = (t_A + 0.0002)$
t_O = thickness of disk at O.

First, it will be necessary to demonstrate that A, B, C and D on the top surface of the disk lie in a plane. Considering AC,

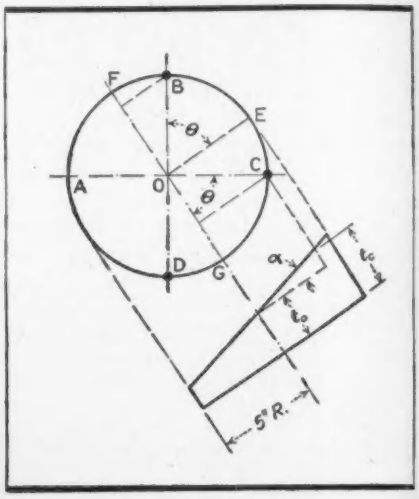
$$t_O = \frac{t_A + t_C}{2} = \frac{t_A + (t_A + 0.0050)}{2}$$
$$= t_A + 0.0025$$

Also, considering BD,

$$t_O = \frac{t_B + t_D}{2}$$
$$= \frac{(t_A + 0.0048) + (t_A + 0.0002)}{2}$$
$$= t_A + 0.0025$$

Therefore, AC and BD intersect at O, and points A, B, C and D lie in the same plane.

Now let E be the high point. Then FG, perpendicular to EO, will be parallel to the bottom surface of the disk.



Let α be the included angle between the faces of the disk, and considering C,

$$\tan \alpha = \frac{t_C - t_O}{OC \sin \theta}$$
$$= \frac{(t_A + 0.0050) - (t_A + 0.0025)}{5 \sin \theta}$$
$$= \frac{0.0025}{5 \sin \theta}$$

Similarly, considering B,

$$\tan \alpha = \frac{t_B - t_O}{OB \cos \theta}$$
$$= \frac{(t_A + 0.0048) - (t_A + 0.0025)}{5 \cos \theta}$$
$$= \frac{0.0023}{5 \cos \theta}$$

Solving for θ,

$$\tan \theta = \frac{0.0025}{0.0023} \text{ or } \theta = 47 \text{ deg. } 23 \text{ min.}$$

Therefore,

$$\tan \alpha = \frac{0.0023}{5 \cos \theta} = \frac{0.0023}{5 \cos 47° \ 23'} \text{ or}$$
$$\alpha = 0 \text{ deg. } 2.34 \text{ min.}$$

Therefore, the high point is 47 deg. 23 min. clockwise from B and the magnetic chuck will have to be set at an angle of 0 deg. 2.34 min. with the grinder table when grinding the top face of the disk.

—W. D. ANDERSON
Norma-Hoffmann Bearings Corp.

SOURCES OF SUPPLY ADDED TO SPECIAL INSERTS

Since publication of the special sections on Electric Motors (PRODUCT ENGINEERING, Dec., 1943) and Hydraulics (PRODUCT ENGINEERING, Feb., 1944) several additional companies have been brought to our attention. In the case of the electric motors insert, Black & Decker Electric Company, Kent, Ohio; F. A. Smith Manufacturing Company, Rochester, N. Y.; and Haydon Manufacturing Company, Forestville, Conn., should be included. To the hydraulics list should be added Sperry Products, Inc., Hoboken, N. J.; Aircraft Accessories Corporation, Burbank, Calif.; Graton and Knight, Inc., Worcester, Mass.; Hydro-Power Systems, Inc., Mt. Gilead, Ohio; Blackhawk Manufacturing Company, Milwaukee, Wis.; General Controls Company, Glendale, Calif.; and Galland-Henning Manufacturing Company, Milwaukee, Wis.

SEPARATING FORCE SHOULD BE INCLUDED WHEN CALCULATING ROTARY GEAR PUMP LOADS

To the Editor:

In answer to Mr. Smith's problem for calculating loads on rotary gear pumps (PRODUCT ENGINEERING, Oct., 1943, p. 674), the first solution in the Dec., 1943, number, page 816, is the general solution for all bearing problems. Only when severe loads are encountered or a low factor of safety is used is it necessary to figure a bearing load in more detail.

In the second solution in the December number a few questions arise in the different formulas. When figuring the hydraulic load, L_1, it is not necessary to include another 2 in the numerator as the load is on the full gear face as explained in the first solution. The mechanical load, L_2, should equal the square root of P^2 plus S^2 and not just P^2 plus S^2. In the total bearing load it is assumed total load per bearing should be L_1 plus $L_2/2$ and not L_1 plus $L_2/4$ as the bearing load is figured on one shaft which has two bearings. When working this problem out in detail it should be continued out one step further and include the separating force of the gears, as the bearing loads are not as great on the drive shaft bearings as the idler shaft bearings. This has been proved by inspection results on many pumps that have been in service over a long period of time.

A sample problem incorporating the separating action of the gears is given below.

A rotary gear pump handles a liquid against 200 lb. per sq. in. discharge pressure at 1,150 r.p.m. developing 5 brake hp. The gear has a 2-in. P.D., 2.5-in. O.D., 3.5-in. face, tooth pressure angle α equals 28 deg. and helix angle β equals 30 degrees.

$$Q \text{ (torque in in. lb.)} = \frac{\text{hp.} \times 63.025}{\text{r.p.m.}}$$

$$Q = \frac{5 \times 63.025}{1{,}150} = 274 \text{ in. lb.}$$

$$P \text{ (tangential force)} = \frac{\text{torque}}{\text{pitch radius of gear}}$$

$$P = \frac{274}{1} = 274$$

S (separating force)

Spur Gears

$$S = P \times \tan \alpha$$

Helical or Herringbone Gears

$$S = P \times \frac{\tan \alpha}{\cos \beta}$$

$$= 274 \times \frac{0.53174}{0.86603} = 168$$

Load on each idler shaft bearing

$$P_1 = \frac{P + \text{load on bearings}}{2 \text{ (for 2 bearings)}}$$

The load on the idler shaft bearings is equal to the O.D. of the gear times the gear face times the pump pressure. Therefore, the load on the idler shaft bearings is equal to

$$2.5 \times 3.5 \times 200 = 1{,}750$$

$$P_1 = \frac{274 + 1.750}{2} = 1{,}012$$

$$S_1 = \frac{S}{2 \text{ (for 2 bearings)}} = \frac{168}{2} = 84$$

$$\text{Resultant} = \sqrt{P_1^2 + S_1^2}$$

$$= \sqrt{1{,}012^2 + 84^2} = 1{,}015$$

Load on each idler shaft bearing = 1,015 lb.

Load on each drive pump shaft bearing

$$P_2 = \frac{\text{Load on bearings} - P}{2 \text{ (for 2 bearings)}}$$

$$= \frac{1{,}750 - 274}{2} = 738$$

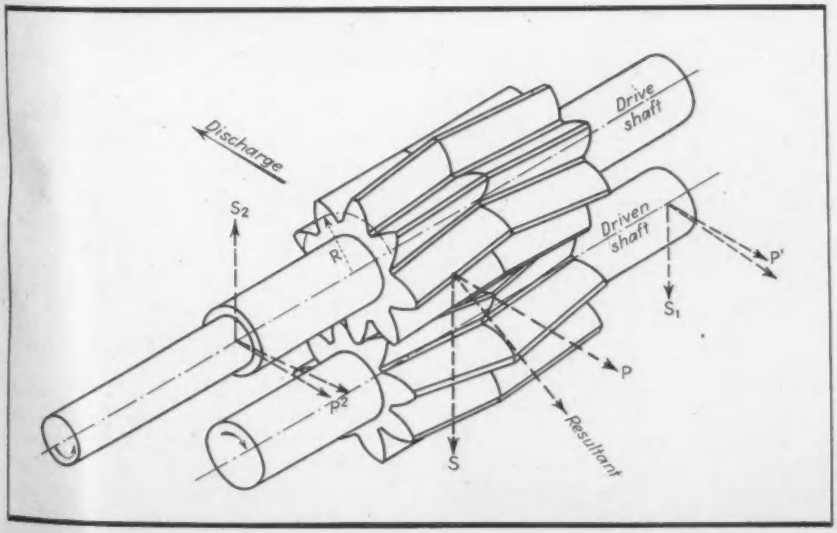
S_2 = Same as S_1

$$\text{Resultant } R_2 = \sqrt{P_2^2 + S_2^2}$$

$$R_2 = \sqrt{738^2 + 84^2} = 741$$

Load on each drive pump shaft bearing = 741 lb.

—WILLIAM J. PFISTERER



Do You Know That—

BELTING made with GR-S synthetic rubber can be joined to natural rubber belting with a vulcanized splice. (15)

HYDROGEN in amounts as small as 0.0005 percent by weight can make steel brittle. (16)

AMERICAN HEAVY BOMBERS of the Flying Fortress and Liberator type each contain about 3,000 lb. of copper and copper alloys. (17)

FIGHTER PLANES of the Thunderbolt and Mustang class each contain almost 700 lb. of copper and copper alloys. (18)

Meetings

Society of Automotive Engineers—National aeronautical meeting, Apr. 5-7, Hotel New Yorker, New York, N. Y.

National Electrical Manufacturers Association—Spring meeting, Apr. 24-27, Palmer House, Chicago, Ill.

American Foundrymen's Association—War production congress and show, Apr. 25-28, Memorial Auditorium, Buffalo, N. Y.

Institute of Aeronautical Sciences—Light plane meeting, Apr. 27, Rackham Memorial, Detroit, Mich.

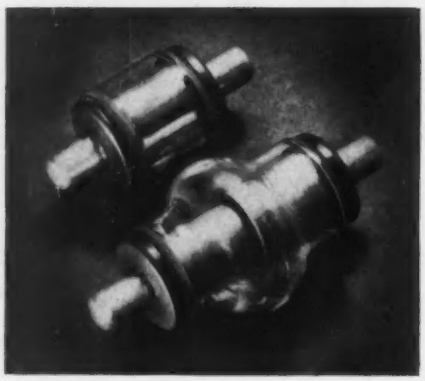
Society of the Plastics Industry—Annual meeting, May 11-12, Edgewater Beach Hotel, Chicago, Ill.

Society of Automotive Engineers—National diesel fuels and lubricants meeting, May 17-18, Hotel Knickerbocker, Chicago, Ill.

NEW MATERIALS AND PARTS

Vacuum Capacitors

Designed for circuits where peak voltages range from 7,500 to 16,000 volts, four new vacuum capacitors have been announced. The first of these, designated as GL-1L 36/GL-36 has a peak voltage of 7,500, 25 micromicrofarad capacitance. Model GL-1L 38/GL-38 has



a peak voltage of 7,500, 50 micromicrofarad capacitance. Model GL-1L 22/GL-492 is rated at 16,000 volts peak, 25 micromicrofarad capacitance. Model GL-1L 23 has a peak voltage of 16,000, 50 micromicrofarad capacitance. One of the principal features of these capacitors is their small size, which permits circuits to be designed more compactly. They are comparatively loss-free since there are no losses in the vacuum dielectric and because the total capacitance is lumped into a volume of about 1 cu. in. The vacuum construction assures constant internal voltage breakdown independent of altitude, temperature, humidity and other factors. Electronics Dept., General Electric Co., 6 State St., Schenectady, N. Y.

All-Purpose Blower

By mass-production of special mountings eight different arrangements of the No. 68 blower are available. These include blower only; blower and stand only; blower and inlet flange only; blower and discharge flange only; blower, inlet and discharge flange only; blower, stand and inlet flange only; blower, stand and discharge

flange only; or blower, stand and inlet and discharge flanges. The housing and stand are made of die-stamped steel and the zinc die-cast multi-blade wheel is dynamically balanced. Wheel and motor are direct-connected. The unit is powered by a series-wound, 110-volt, single-phase, 60-cycle, sleeve-bearing, a.c. motor that operates at 3,400 r.p.m. Ilg Electric Ventilating Co., 2850 N. Crawford Ave., Chicago 41, Ill.

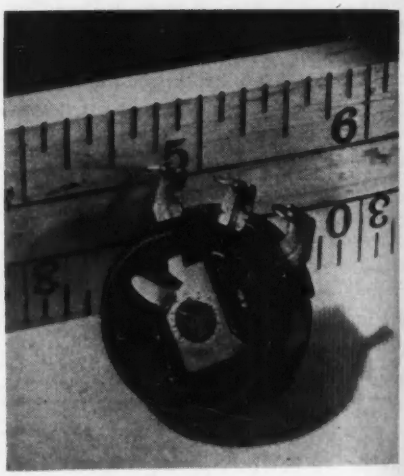
Portable Tensile Tester

Rapid insertion and removal of test specimens through adoption of a new holder features the redesign of a portable tensile testing machine. Although seven intermediate and interchangeable

indicators from 0-250 to 0-10,000 lb. can be used, the unit weighs 132 lb. and is 35 in. tall. The machine is hand-driven, but it can be motorized and can be had with a metal floor cabinet, which provides space for specimens and a shelf for a motor. W. C. Dillon & Co., 5410 W. Harrison St., Chicago 44, Ill.

Wire-Wound Control

Available in resistance values up to 10,000 ohms and rated at 1½ watts, the Type 43 wire-wound control is designed to save space. The unit measures 1⅛ in. in diameter by $\frac{7}{16}$ in. behind the mounting surface. The phenol plastic body is completely inclosed by the dust-tight metal cap, or by the attached switch. The wire winding is curved and held in a concentric slot in the molded



body. The alloy contact arm presses against the inside surface of the winding. The control is supplied with or without switch in linear tapers only. Clarostat Mfg. Co., 285 N. Sixth St., Brooklyn, N. Y.

Marine-Type Rotary Pump

Operating on the swinging-vane principle, a marine-type rotary pumping unit with built-in relief valve is designed particularly for handling Navy lube oil. The unit has a capacity of 50 gal. per min. at a discharge pressure of 20 lb.

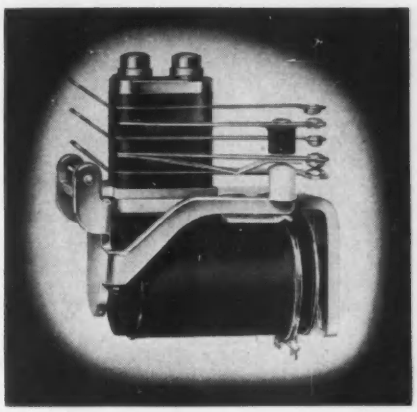
per sq. in. and is connected directly by a flexible coupling to a 3-hp. motor which drives the pump at 870 r.p.m. The bearings are internal anti-friction type and a split gland is used for ease in repacking. The motor is supported by a bracket made of welded steel plate which is bolted to a bulkhead. The pump is mounted vertically on the base of the bracket, permitting access for lubrication and adjustment. Blackmer Pump Co., Grand Rapids 9, Mich.

Fluid-Friction Brake

Control or automatic governing of the speed of a machine equipped with a power take-off shaft is provided by the Hydrotarder. Resistance is created entirely by the friction of water as it circulates in the unit. Energy is dissipated as heat as the water is circulated. The amount of resistance depends on the speed of operation of the machine and is adjusted by regulating the rate of circulation of the water. There is no mechanical friction. The unit does not operate under pressure. The rotor which operates inside the housing or stator, is the only moving part. Typical applications include dynamometers, running-in brakes, brakes for expansion engines, tension reels or roll, automotive vehicles and acceleration brakes for spinning machines. Parkersburg Rig & Reel Co., Parkersburg, W. Va.

Telephone-Type Relay

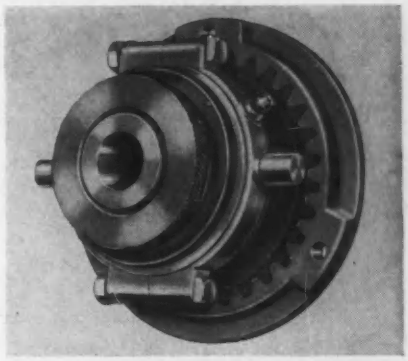
Two models, TSU and TSL, make up a line of telephone-type relays. Model TSU, illustrated, for bottom mounting, is suitable for crystal-switching, high-frequency, plate-circuit and general-utility applications. Model TSL is for



end mounting. Contact arrangement supplied can be normally open, normally closed, single-pole double-throw, or any two combinations. Contacts will carry 2 amp. up to 24 volts d.c. and 115 volts a.c., non-inductive load. Coil resistances are available from a fraction of an ohm to 5,000 ohms. The relays will withstand vibrations up to 10 G. and meet standard salt spray and humidity specifications. Over-all dimensions are 1¼ x ¾ x 1½ in. Weight is 1¼ oz. Either ceramic or phenol-plastic insulation is provided. Dept. T, Allied Control Co., 2 East End Ave., New York 21, N. Y.

Friction Clutch

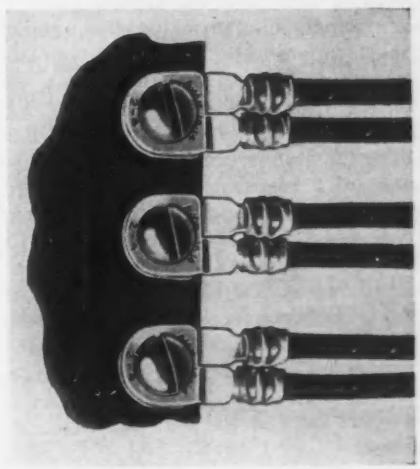
For use where power requirements are relatively small, a Rolling-Grip friction clutch is made with a 3½-in. dia. disk rated at ½ hp. at 100 r.p.m., or with a 4½-in. dia. disk rated at 1 hp. at 100 r.p.m. Polished hardened steel balls are forced into a V-shaped groove by a hardened-steel cam in operating the clutch. Forcing the balls toward the center of the shaft widens the V-shaped groove. This applies pressure on the friction surface. Adjustment is controlled by a threaded collar locked in place by set screws. The clutch can be provided with a gear-tooth friction disk



and drive ring or with a bolted friction disk, either type being suitable for operation under dry conditions. If operation in oil is required the asbestos-fiber friction disk can be replaced with thin metal disks. The cam-and-thrust ring contours can be altered to change the clutch characteristics. There are no exposed operating parts. Smooth-finished die-castings are used for the slip ring and drive ring. Dodge Mfg. Corp., Mishawaka, Ind.

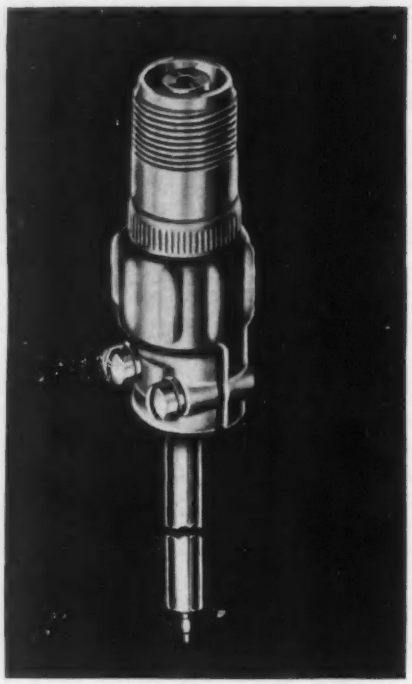
Two-Way Terminal

Lateral motion which might cause short-circuiting between adjacent terminal groups is eliminated in a two-way terminal with an interlocking principle. Thus, two or more terminals are used on a single stud and held together to prevent them from contacting terminals on adjacent studs. Dept. Q, Aircraft-Marine Products, Inc., 1521 N. Fourth St., Harrisburg, Pa.



Fire Detector

Intended primarily for use in engine and accessory sections of aircraft are a continuous- and a unit-type fire detector. The former is a copper-plated fusible-alloy tube containing inorganic insulating beads which support a conductor wire. Flame applied to the assem-



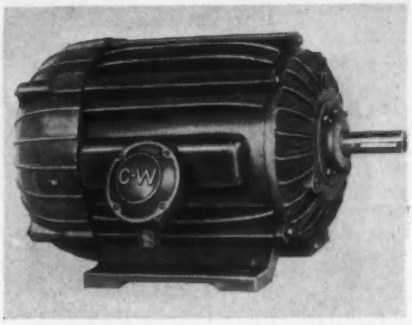
bly causes the tin alloy to melt, filling the spaces between adjacent beads and completing the circuit between the conductor wire and the grounded tube. Ordinary backfires will not cause a false alarm. The unit type uses the Thermoswitch principle in which temperature detection is based on an expanding shell which separates two silver contacts carried on curved Invar struts under high spring tension. Contacts can be arranged to either close or open circuit on temperature increase, as required. This type will withstand repeated temperatures of 2,000 deg. F., without damage or change in the calibration point. Specifications of the continuous type are weight, 1.5 oz. per foot; diameter, $\frac{7}{32}$ in.; melting point of alloy, 350 deg. F., minimum bending radius, 1.5 in.; insulation, 1,000 volts breakdown and resistance of 3 megohms at 500 volts d.c.; and maximum length 7.5 ft. The unit type detector has a current rating of 10 amp. maximum at 115 volts, and 5 amp. maximum at 230 volts. When used on d.c. a small condenser may be required. Weight is approximately 3 oz., calibration point is 350 deg. F., response time is 1 to 2 sec. with 2,000 deg. F. flame. Fenwal Inc., 30 Pleasant St., Ashland, Mass.

Corrosion Neutralizer

Protection of steel parts during processing against such corrosive influences as acid perspiration, chemical atmospheres, fumes and high humidity is provided in Cosmoline No. 805. This material affords protection by neutralizing the causes of corrosion rather than removing corrosion itself. It is a fluid that conforms to requirements of Ordnance Technical Manual TM38-305 and will exceed the 24-hr. salt-spray and 100-hr. humidity tests. E. F. Houghton & Co., 240 W. Somerset St., Philadelphia, Pa.

Corrosion-Resistant Motor

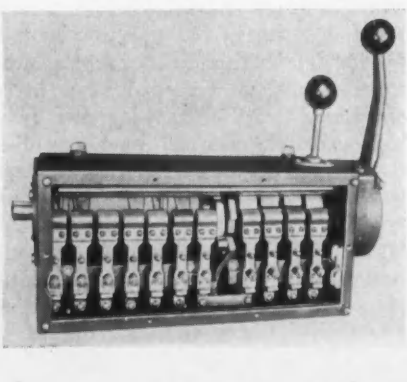
Suitable for operation in atmospheres containing moisture dust, vapors or gases like those in chemical and food plants, textile mills and mines, the Sealedpower electric motor is available in sizes from 1 to 15 hp. It can be furnished for operation from any polyphase power supply. The unit is a totally-inclosed, fan-cooled type, but there



are no cooling ducts. All exposed parts are acid and alkaline resistant. In addition to mechanical sealing of the entire motor, each coil is individually sealed by vacuum impregnation. Crocker-Wheeler Div., Joshua Hendy Iron Works, Ampere, N. J.

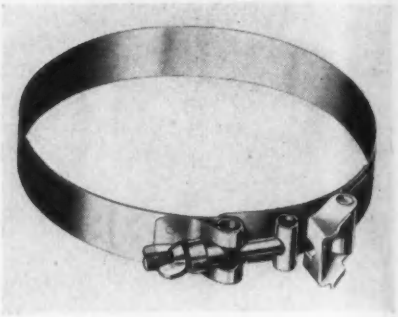
Reversing Controller

Economy in current consumption is a feature of the M-79 simplified four-speed reversing controller for electric and gas-electric trucks. Resistance is used only on the first speed. Additional power saving is attributed to the manipulation of the motor fields, connecting them in series on first and second speeds. The welded housing is dust tight and meets specifications for flash-proofing. Elwell-Parker Electric Co., Cleveland, Ohio.



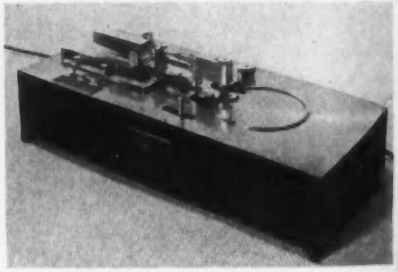
Adjustable Snap Clamp

Features of a snap-on latch are combined with the adjustment of a standard clamp in the Quick-Coupler. This permits instantaneous removal or quick installation of the clamp. It is available in a variety of sizes made from aluminum alloy or stainless steel and in shapes to fit all convex surfaces. Self-locking, plain hex or wing nuts can be had. Marman Products Co., 940 W. Redondo Blvd., Inglewood, Calif.



Piloting Fixture

Surface roughness of top and side surfaces of all types of rings is inspected with the Type R piloting fixture, which works in conjunction with any Profilometer. The ring can be measured by tracing circumferentially, radially at one place and a combination of both.



The tracer is automatically advanced and retracted as each ring is measured. Rings are easily inserted and removed and only slight adjustment is needed to handle rings with inside diameters varying from 2 to 10 in. Weight of the fixture is 95 lb., and size is 10 x 22 x 7½ in. Operation is from 150-volt, 60-cycle current. Dept. 7, Physicists Research Co., 343 S. Main St., Ann Arbor, Mich.

Midget Switch

Actuation from either the top or the bottom are features of a midget switch built on the rolling-spring principle. All parts are non-corrosive. The switch is adapted to electronic control devices, machine tools, aircraft and electrical appliances. It has withstood winteriza-

Disposal of Government War *Plants and* Equipment

In the last four years, the Federal Government has spent over fifteen billion dollars on war plants—two-and-one-half times as much as was spent by private investors.

Of this fifteen-billion-dollar government investment, about one-third has gone into facilities for the manufacture of aircraft and for ship construction and repair; another third has gone into plants for production of combat ordnance; and the remaining third has gone into a variety of facilities for making synthetic rubber, metal products, machinery, and miscellaneous equipment.

Most of these plants are in industries that are expanded far beyond peacetime requirements. Furthermore, their convertibility to other civilian uses will, in many cases, be complicated by their specialized equipment and layout, by their tremendous size, and by their uneconomic location. At the moment, it looks as if roughly one-third of the government-owned plants and equipment can be converted fairly readily to peacetime operation, and will, therefore, be easily disposable to private enterprise.

The discovery of unsuspected uses for war plants and equipment may well raise the disposable proportion to one-half or more. The government, at the end of the war, may own about one-eighth of the commercially-usable industrial capacity of the country. It will be by far the largest owner of machine tools; it will own enormous aluminum capacity, magnesium capacity, many miles of pipe lines, and more ships than the entire private shipping industry.

What the government does with its war plants will have a profound effect on the free enterprise system and on all workers, employers, investors, and consumers who have a part in that system. If this problem is handled badly, we may find ourselves enmeshed in a trend toward monopoly and government operation of industry. If the problem is handled well, we shall have taken a big step toward freedom of action in a competitive society, toward full opportunities for business enterprise, toward well-paid productive jobs for workers, and toward a higher standard of living for us all.

Recently, three important events have signalled encouragement. They are the report of Senator George's Committee, the Baruch report, and the report of Senator Truman's Committee. These reports are noteworthy for their competent sizing up of a complex problem, for their recognition of the major responsibility of government in making a successful transition to peace, for their insistence on wise policy and good administration, and for their genuine concern that our productive powers be given full opportunity in a free private enterprise system. These reports agree on basic principles and many specific lines of action. There are, however, important areas of policy formation, organization, and procedure—especially in regard to plant disposal—which remain to be blue-printed.

In formulating the policies and practices to be followed in dealing with government war plants, our major goal must, of course, be a high level of production and employment in private business after the war.

Government operation in competition with private employers and privately-employed workers will not be desirable because it will make investment unattractive to private capital and will limit opportunities for private employment. On the other hand, sales to private buyers which result in increasing the concentration of industry will also be undesirable. We must use this opportunity to strengthen the competitive enterprise system and to move away from, not toward, the concentration of economic power in either public or private agencies.

To accomplish these objectives, a program of action such as follows will be necessary:

1. An adequate reconversion organization will be needed in the government, but its powers and responsibilities should carefully be defined by Congress. Fortunately, an able Administrator of Surplus War Property already has been appointed. It will be essential for him to work in closest cooperation with Congress and with the Armed Forces and other executive agencies. The Office of War Mobilization, and ultimately the President, must be responsible for seeing that the Surplus War Property Administration is not sidetracked by the operating agencies and is not dominated by their sheer size. Funds must be supplied generously to the Surplus War Property Administrator, so that he can set up an organization adequate to cope with this huge and complex job. Business, too, must be generous in loaning top-flight executives for postwar government service.

2. One of the first acts of the Surplus War Property Administration will have to be to assemble a complete inventory of government war plants and equipment, to make possible the planning and control of the disposal process, and to form the basis of catalogues of property available for sale.

3. Cooperation between the executive and legislative branches of the government will be needed to develop at least tentative plans with respect to matters of public policy which are of special importance to a successful transition to peace. Among these matters are the size of the military establishment to be maintained in time of peace, the stand-by facilities and reserves of materiél necessary for our security in case of future war, and our policy regarding import and production of synthetic rubber and other critical and strategic materials.

4. The Surplus War Property Administrator should

obtain from the Armed Forces, acting under congressional directives, specification of those plants which are needed to supply our peacetime Army and Navy and to provide the essential reserve capacity in case of war.

5. The Surplus War Property Administrator should select certain war plants as depots in which to store the huge surpluses of inventories and equipment which will have to be removed from private and government-owned factories in order to make possible their conversion to civilian use.

6. Those plants which are not desired by the Army or the Navy, which are not needed for storage, and which clearly will be unsuitable for peacetime utilization should be scheduled for dismantling and disposal piecemeal.

7. The two or three billion dollars' worth of government facilities intermingled with private plant should receive attention with a view to early sale, temporary continuance or use under lease, or early removal.

8. The various plants and pieces of equipment available for sale to private business should be classified conveniently, catalogued, and advertised to prospective buyers or lessors. Before the Surplus War Property Administrator offers, for private sale, plants and equipment not desired by the Army or the Navy, he should ascertain whether the plants or equipment are desired by other branches of the government or by public corporations such as the T.V.A.

9. Whenever property can be sold at prices approximating depreciated reproduction cost, that will be by far the best solution. Generous time-payment terms should be offered. In many cases the government may be unable to sell the property for reproduction cost less depreciation, for the simple reason that no one would think of reproducing it. The property may already be partly obsolete or, because of its size, location, or other characteristics, may only be moderately well suited for commercial use. This should not prevent the government from selling it, provided a price which fairly represents the worth of the property can be obtained. The best test of that worth is the price produced by active bidding under favorable market conditions.

10. When property cannot be sold at a fair price, temporary leases with options to buy should be employed to get the facilities into productive use. This should not, however, be done on terms which would cause unfair competition or create clearly excessive capacity in an industry. And the lease must be temporary; it must not be the means to prolong government control or ownership.

11. The government should offer the strongest possible resistance to local groups or industry groups seeking subsidies for continued operation of war properties. Subsidies will burden the Treasury and lead to inefficient use of resources. They will be justified only to maintain facilities needed for national security.

12. The plants and equipment offered for sale and lease should include sufficient quantities in small enough lots to satisfy the demands from small business. The war has tended to concentrate production in larger plants. After the war, we should seek a wider distribution of the government war facilities.

13. Insofar as possible, war buildings and equipment should be offered for sale in units which can be purchased by businesses in peacetime industries. Many of these industries have had to get along during the war without adequate replacement and expansion, and will be ready to buy if they are able to get what they want from the government. This is a particularly desirable market for surplus government property since these industries are, for the most part, not faced with the problems of excess capacity.

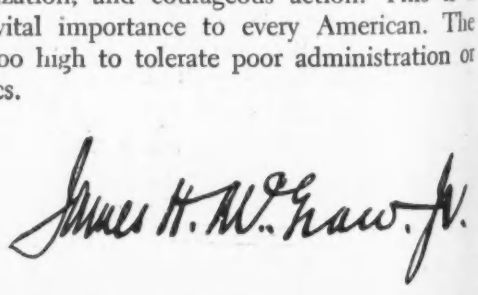
14. Property, such as machinery and other movable equipment, which is in excess of our domestic requirements or is more urgently needed by other countries, should be exported. We shall need, and can take, large supplies of raw materials in return.

15. Property which is not needed by the Armed Forces, which cannot be sold or leased on terms which would be fair to competing plants, which cannot be dismantled and distributed piecemeal, and which cannot be sold abroad, should be scrapped as soon as its non-disposability is apparent. The disposal of war plants should be completed within three to five years.

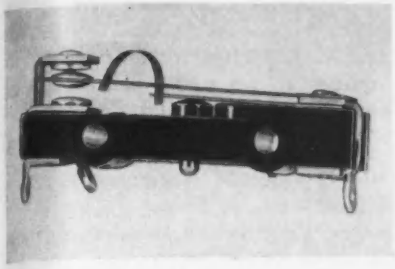
16. All negotiations for sale or disposal should be matters of open public record. As Mr. Baruch has said, the process must be conducted in a goldfish bowl. This is as much for the protection of business as for the protection of the government.

These courses of action do not include everything that must be done, but they do indicate the general lines along which our surplus war plant disposal must proceed if it is to avoid precipitating needless transition unemployment.

The gravest danger of all will be red tape, intergovernmental conflict, and inadequate administration. It would be a great misfortune for the executive and legislative branches to quarrel over details of organization when they agree on the basic principles to be followed in handling the problem. Obviously, the Surplus War Property Administration must cooperate with Congress and look to it for policy guidance. Just as obviously, the disposal problem will involve great difficulties of administration which must not be complicated by congressional interference. We shall need the best we can get in careful policy making, detailed planning, good organization, and courageous action. This is a matter of vital importance to every American. The stakes are too high to tolerate poor administration or petty politics.



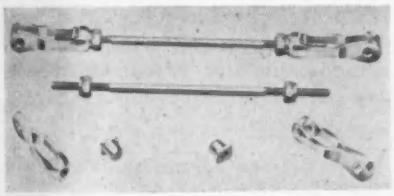
President, McGraw-Hill Publishing Company, Inc.



tion, salt-spray and high- and low-temperature tests. The snap action spring and the center blade are made of beryllium and the base is of phenol plastic. When built into relays smaller coils may be used because only 4- to 6-oz. operating pressure is required. The switch is furnished in single pole, normally open, normally closed, and double throw, with both pre-travel and over-travel provided. It is 1½ x 7/16 x 7/16 in. in size, and weighs less than 1 oz. Acro Electric Co., 1310 Superior Ave., Cleveland 14, Ohio.

Clevis Rod End

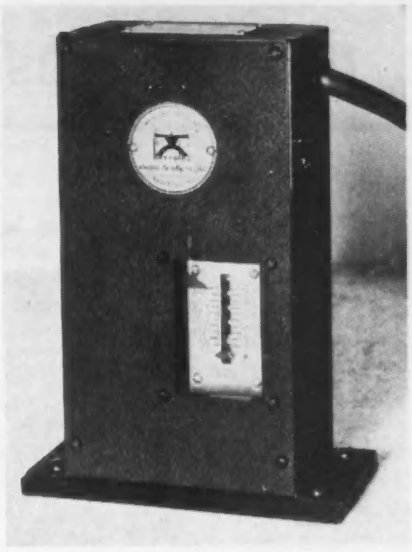
Available in both fork and eye types, clevis rod ends make use of the Socketype terminal developed about a year ago. The end consists of a Socketnut



which holds the terminal against a hex nut. Both are drilled for lock wires. The terminals are stamped from alloy steel and cadium plated. The Socketnut is produced with right- or left-handed threads and with opposite sides slightly flattened to allow tightening with an end wrench. It fits snugly in the socket of the terminal into which the rod end goes. Rod ends of 4-40, 8-32, 10-32, 12-24, ¼-28, 7/16-24, and ⅜-24 sizes are available. Poulsen & Nardon, Inc., 2665 Leonis Blvd., Los Angeles 11, Calif.

Pressure-Control Switch

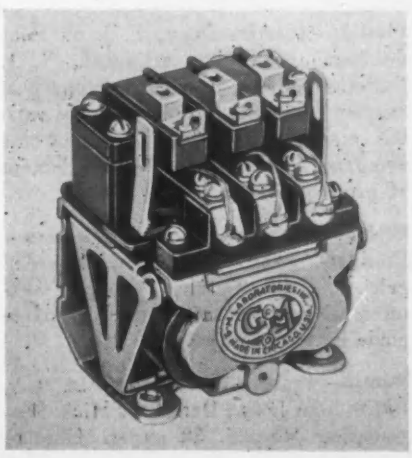
For solenoid-operated valves, automatic control of operating cycles on hydraulic machines, control of pumps or compressors and operating and safety controls for chemical and oil processing equipment, a pressure-control switch has a control element that is a pressure gage of the direct-action type. It is designed to withstand shock loads on surging lines. Accuracy is maintained over long periods of time and overloads do



not affect the gage, which actuates a snap-action switch. All switches are of single-pole construction and are available with normally closed, normally open or double-throw contact arrangements. Also available is a maintained-contact type switch with manual reset. Pressure connection is provided for ¼-in. American Standard pipe tap and electrical connection is provided for ¾-in. conduit. The switch is mounted on a cold-rolled steel base with two 7/16-in. dia. mounting holes and is covered by a 14-gage sheet-metal housing with removable front. A methyl methacrylate window protects the gage. Electrical ratings are 10 amp. at 125 volts—5 amp. at 250 volts, a.c.; 3 amp. at 460 volts—2 amp. at 200 volts, a.c.; ½ hp. at 115, 230 or 460 volts, a.c. Hercules Electric & Mfg. Co., 2416 Atlantic Ave., Brooklyn 33, N. Y.

Multi-Pole Relay

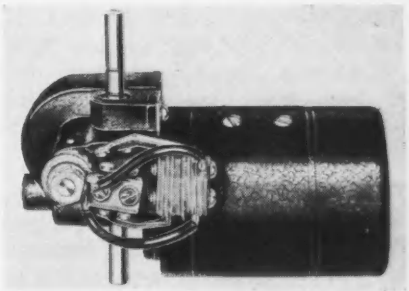
Designed for use in electronic circuits, Type 27 relay is small, rugged and has high contact capacity in relation to size. It is suitable for use on aircraft and mobile equipment where vibration is



encountered. It is available with various numbers of poles and each blade is shimmed to correct adjustment. The relays in 1-, 2- and 3-pole units are approximately 1⅝x1 13/16x2 in. in size, and the 5-pole unit is approximately 2x2½x 2⅛ in. Weight varies from 4½ to 6½ oz. Vibration and acceleration resistances are rated to 10 G. Contact is up to 10 amp. depending on available power and on coil and circuit characteristics. Contact pressure ranges from 30 to 50 grams. G-M Laboratories, Inc., 4309 N. Knox Ave., Chicago 41, Ill.

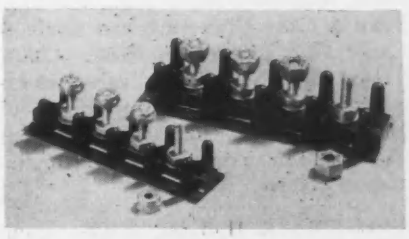
Gear Unit

Preventing over-run is a feature of the Model B-1 gear unit that stops a motor almost instantaneously by means of a brake applied in either direction of rotation, or the reversibility of the motor to which it is applied. It is available for mounting on fractional horsepower motors. Electric Motor Corp., 1204 State St., Racine, Wis.



Connector Panel Assemblies

Built around NAS17 and NAS18 molded terminal blocks to which are added five pieces of hardware and a laminated phenolic insulating strip, the P1 and P3 connector panel assemblies are supplied as complete items ready



for installation. They can be ordered in varying lengths to suit requirements as to number of posts needed and available room in junction boxes. The terminal blocks are compression molded of medium-impact, macerated-fabric-filled phenolic material. All components are in accordance with nationally recognized standards acceptable to manufacture of Army and Navy aircraft. Plastic Manufacturers, Inc., Stamford, Conn.

Manufacturers' Publications

Hydraulic Control — Adel Precision Products Corp., Burbank, Calif. Bulletin, 16 pages. Announces Isodraulic control, a system for remote positioning control by hydraulic pressure, featuring schematics, tables and text to explain possibilities.

Wiring Devices—Aircraft-Marine Products, Inc., 1591-R Fourth St., Harrisburg, Pa. Catalog SD-1, 72 pages. Solderless insulation support terminals, standard and flag-type terminals, connectors, lighting contacts, cable lugs, wiring plugs, standard and quick-connect bonding jumpers, splicing terminals, grid clips, hand tools, installation presses and crimping dies are illustrated and described and a section is devoted to wire reference data.

Wax Coating—Dept. PE, Enthone Co., 442 Elm St., New Haven, Conn. Bulletin, 4 pages. Emulsion waxes applied at room temperature and which form hard, rust-inhibiting films on metal are described.

V-Belts and Sheaves — Allis-Chalmers Mfg. Co., Milwaukee 1, Wis. Bulletin B6249, 44 pages. Simplified engineering data for fractional-horsepower Texrope V-belts and sheaves are presented in the form of working formulas, installation protographs, line drawings and selection tables.

Hydraulic Valves—R. D. Wood Co., 400 Chestnut St., Philadelphia 5, Pa. Catalog, 38 pages. High-pressure hydraulic valves of various types are illustrated and described.

Valve Selector—Dept. S.P., Reading-Pratt & Cady Div., American Chain & Cable Co., Bridgeport, Conn. Chart, 11½x17 in. Selection of valves is explained by a simplified breakdown of conditions and an explanation of what these conditions determine in the operation of a valve.

Steels—W. J. Holliday & Co., Hammond, Ind. Bulletin, 32 pages. Speed Case—a low-carbon, open-hearth, free-machining steel—and Speed Treat—a medium-carbon, open-hearth, high-tensile, free-machining steel—are described in detail and many uses are explained and illustrated.

Instruments—C. J. Tagliabue Mfg. Co., Park and Nostrand Aves., Brooklyn, N. Y. Catalog 1101H, 40 pages. Celectray electric thermometers, pyrometers, photoelectrically balanced recorders, indicators, controllers, potentiometers for thermocouples and slide-wire wheatstone bridges for resistance thermometers are described and their uses covered.

Flexible Shafting—Stow Mfg. Co., 445 State St., Binghamton, N. Y. Book No. 441, 32 pages. What flexible shafting does and where it can be used are explained.

Coolant Pumps—Ruthman Machinery Co., 1823A Reading Rd., Cincinnati 2, Ohio. Catalog, 60 pages. Complete data, including drawings, of the entire line of Gusher coolant pumps and accessories are given in seven sections, each of which covers a particular type of pump or accessory.

Air Condensers—Barker & Williamson, 235 Fairfield Ave., Upper Darby, Pa. Catalog 75C, 4 pages. Features of Type CX variable air condensors are presented.

Flange Packing—Packings Dept., Graton & Knight Co., Worcester 4, Mass. Bulletin, 4 pages. Reprint of PRODUCT ENGINEERING advertisement defines flange packings, points out advantages, illustrates uses, lists design features and reviews case studies.

Insulating Varnish — Sterling Varnish Co., 167 Ohio River Blvd., Haysville, Pa. Bulletin 243, 4 pages. Describes Speedairbonds, a group of air-drying insulating varnishes for electrical equipment.

Electronic Control — General Electric Co., Schenectady, N. Y. Bulletin GEA-4126, 12 pages. Fundamentals and applications of electronic control are described and illustrated.

Plastics—Plastics Dept., E. I. du Pont de Nemours & Co., Arlington, N. J. Bulletin A-3997, 8 pages. Properties, characteristics and applications of various plastic materials supplied by the company are presented for the benefit of product designers.

Hydraulic Valves — American Screw Products, 7000 Avalon Blvd., Los Angeles 3, Calif. Catalog, 8 pages. Features various aircraft hydraulic valves made by the company.

Pumps—Pioneer Pump & Mfg. Co., 19679 John R St., Detroit 3, Mich. Engineering Manual, 88 pages. How to determine size of pumps and pump-capacity requirements, and how to make proper pump installations is told in addition to describing and illustrating company's Pioneer and Rollway lines of coolant and lubricant pumps.

Motors—Electric Machinery Mfg. Co., Minneapolis 13, Minn. Folder 173, 4 pages. Construction and design of synchronous motors and control from 300 hp., 500 r.p.m. up are shown.

Belt Fasteners—Jewell Belt Hook Co., Naugatuck, Conn. Folder, 6 pages. Illustrates clinch-type Jewell Potter belt hooks and lists numbers of hooks required for various kinds and widths of belts.

Flexible Couplings — Automatic Machine & Tool Co., 132 Charles St., Auburndale, Mass. Folder, 4 pages. Shows details of construction and lists dimensions of various sizes of Multiflex flexible couplings.

Drive—Link-Belt Co., 307 N. Michigan Ave., Chicago, Ill. Bulletin 1991, 20 pages. Contains tables for use in computing center distances and chain lengths of chain drives for operation of cut-tooth wheels.

Combustion Equipment—Hauck Mfg. Co., 130 Tenth St., Brooklyn, N. Y. Book, 112 pages. Contains reference material on the determination, selection, installation and operation of combustion methods and industrial oil and gas burners and equipment.

Pressure Gage—Manning, Maxwell & More, Inc., Bridgeport 2, Conn. Bulletin, 12 pages. Explains by text and illustrations the design and construction of the Duragauge, a pressure gage for numerous purposes.

Pumps—Worthington Pump & Machinery Corp., Harrison, N. J. Bulletin W-321-B7C, W-321-B13B, W-321-B14 and W-321-B15, 4 pages each. Different type of Monobloc centrifugal pump is described in detail in each bulletin.

Wiring Duct—Square D Co., 6060 Rivard St., Detroit 11, Mich. Catalog Section 6000, 36 pages. Description and application data, including illustrations, for Saflex Plug-in duct, Saflex feeder duct and Square-Duct are presented.

Belt—Dayton Rubber Mfg. Co., Dayton, Ohio. Catalog 280, 384 pages. Data on selection of V-belt, V-flat, Speed-up V-belt and special drives are featured along with significant engineering information.

Fasteners—Reliance Div., Eaton Mfg. Co., Massillon, Ohio. Folder 101, 6 pages. Provides tabular and descriptive information on Springtite Semblies.

Plate Diameters For Formed Domes and Heads

JOEL EKLUND

FORMULAS given here are based on the assumptions that the plates will retain their thickness during forming operations, and that the gross areas of the formed heads are equal to the areas of the circular blanks. While this is not strictly true, since the plates will stretch during the forming operation, the stretch is ordinarily small even for thick plates. Any calculations based on a consideration of the stretch resulting from the flow of metal would be complicated and uncertain. Since an allowance should always be added to the blank diameter for machining the edge, any small stretch will be of minor importance.

In the formulas developed for flat heads with corner radius, conical heads with corner radius, and heads of the spherical, two radii, and elliptical types, the radii applies to the bend lines in the metal according to Poisson's ratio or as otherwise determined. The mean radii to the center of the plates can be used in most cases, or the inside radii of very thin plates, with little inaccuracy in the results.

FLAT HEADS WITH CORNER RADIUS

D = dia. of blank, in.
R_1 = radius of cylindrical flange portion, in.
R_2 = corner radius, in.
F = width of cylindrical flange, in.
Area of flange portion, sq. in. $= 2\pi R_1 F$
Area of corner radius portion, sq. in.
$= \pi R_2 [\pi(R_1 - R_2) + 2R_2]$
$= 9.8696 R_1R_2 - 3.5864 R_2^2$
$= 3.5864 (2.7519 R_1R_2 - R_2^2)$
Area of flat portion, sq. in. $= \pi (R_1 - R_2)^2$
Total area of blank, sq. in.

$$= \frac{\pi D^2}{4} = 2\pi R_1F + \pi R_2 [\pi (R_1 - R_2) + 2R_2] + \pi (R_1 - R_2)^2$$

$$= \pi(2R_1F + R_1^2 + 1.1416 R_1R_2 - 0.1416 R_2^2)$$

Diameter D of blank is

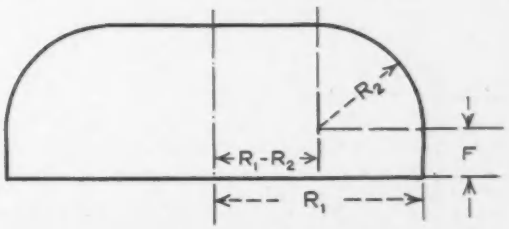
$$D = 2\sqrt{2R_1F + R_1^2 + 1.1416 R_1R_2 - 0.1416 R_2^2}$$

When large heads are to be made from plate sectors and the contours of the sectors are laid out before the sectors are formed, the length L of the plate over the corner radius is

$$L = \pi R_2/2$$

Width contours over the sectors can be found by dividing the length L into a number of parts or bands. The full circumferential width W of each band or part is

$$W = 2\pi (R_1 - R_2 + R_2 \cos \phi)$$



in which ϕ is the angle made by a line normal to the band and a line normal to the corner bend at the large radius R_1 in a radial plane section of the formed sector. When the sector is laid out in 9 bands of 10 deg. each, angles for ϕ are taken in 10 deg. increments beginning with 5 deg. for the first band. For the second band ϕ is 15 deg., for the third ϕ is 25 deg., and so on until ϕ is 85 deg. for the ninth band.

The band widths for each sector are then found by dividing the circumferential widths by the number of sectors.

TWO RADII HEADS

D = dia. of blank, in.
R_1 = radius of cylindrical flange portion, in.
R_2 = corner radius, in.
R_3 = radius of dome, in.
β = angle subtended by corner radius R_2, deg.
$= \cos^{-1}[(R_1 - R_2)/(R_3 - R_2)]$, by construction
Area of flange portion, sq. in. $= 2\pi R_1F$
Area of corner radius portion, sq. in.
$= 2\pi R_2[\beta(R_1 - R_2)/57.3 + R_2 \sin \beta]$
Area of dome radius portion, sq. in.
$= 2\pi R_3^2 (1 - \sin \beta)$
Total area of blank, sq. in.

$$= \frac{\pi D^2}{4} = 2\pi \left\{ R_1F + R_2 \left[\frac{\beta (R_1 - R_2)}{57.3} + R_2 \sin \beta \right] + R_3^2 (1 - \sin \beta) \right\}$$

Blank dia. D, in., is

$$D = \sqrt{8 \left\{ R_1F + R_2 \left[\frac{\beta (R_1 - R_2)}{57.3} + R_2 \sin \beta \right] + R_3^2 (1 - \sin \beta) \right\}}$$

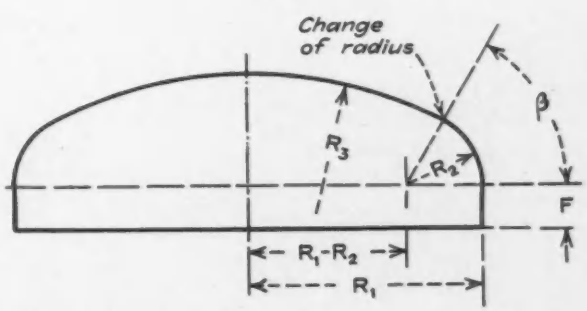


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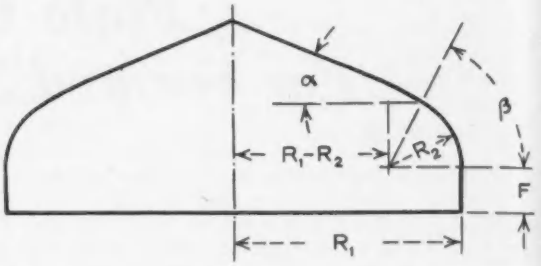
Plate Diameters for Formed Domes and Heads *(continued)*

CONICAL HEADS

D = dia. of blank, in.
R_1 = radius of cylindrical flange portion, in.
R_2 = corner radius, in.
F = width of cylindrical flange, in.
α = interior angle formed by a radial section of conical portion and a plane normal to axis of cylindrical portion, deg.
β = angle subtended by corner radius R_2, deg.
$= 90 - \alpha$



Area of flange portion, sq. in. $= 2\pi R_1 F$
Area of corner radius portion, sq. in.
$= 2\pi R_2[\beta(R_1 - R_2)/57.3 + R_2 \sin \beta]$
Area of conical portion, sq. in.
$= \pi (R_1 - R_2 + R_2 \cos \beta)^2 / \cos (90 - \beta)$
Total area of blank, sq. in.

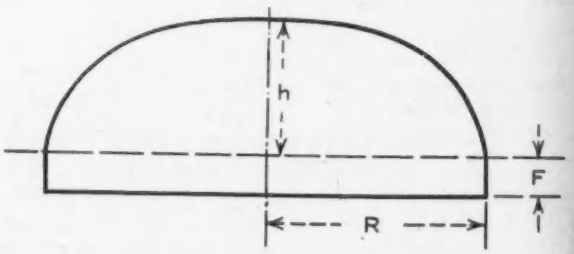
$$= \frac{\pi D^2}{4} = \pi \left\{ 2 R_1 F + 2 R_2 \left[\frac{\beta (R_1 - R_2)}{57.3} + R_2 \sin \beta \right] + \frac{(R_1 - R_2 + R_2 \cos \beta)^2}{\cos (90 - \beta)} \right\}$$

Diameter D of blank, in., is

$$D = 2 \sqrt{2 R_1 F + 2 R_2 \left[\frac{\beta (R_1 - R_2)}{57.3} + R_2 \sin \beta \right] + \frac{(R_1 - R_2 + R_2 \cos \beta)^2}{\cos (90 - \beta)}}$$

ELLIPTICAL HEADS

D = dia. of blank, in.
R = radius of cylindrical flange portion, also half of major axis of ellipse, in.
F = width of cylindrical flange, in.
h = height of elliptical dome portion, also half of minor axis of ellipse, in.



Area of flange portion, sq. in. $= 2\pi RF$
Area of dome portion, sq. in.

$$= \pi \left[R^2 + \frac{h^2}{2x} \log_e \left(\frac{1 + x}{1 - x} \right) \right]$$

in which x is the eccentricity of ellipse, or

$$x = \sqrt{1 - \frac{h^2}{R^2}}$$

Total area of blank, sq. in.

$$= \frac{\pi D^2}{4} = \pi \left\{ 2 RF + R^2 + \frac{h^2}{2x} \log_e \left(\frac{1 + x}{1 - x} \right) \right\}$$

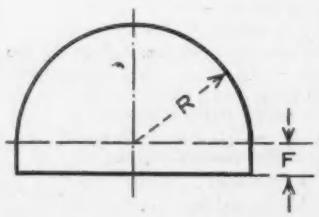
$$D = 2 \sqrt{2 RF + R^2 + \frac{h^2}{2x} \log_e \left(\frac{1 + x}{1 - x} \right)}$$

Heads of the elliptical type are frequently made with the minor axis equal to one half the major axis, in which case the diameter D of the blank is

$$D = 2 \sqrt{2 RF + 1.3799 R^2}$$

SPHERICAL HEADS

D = dia. of blank, in.
R = radius of cylindrical flange portion, also radius of head, in.
F = width of cylindrical flange, in.



Area of flange portion, sq. in. $= 2\pi RF$
Area of spherical portion, sq. in. $= 2\pi R^2$

Total area of blank, sq. in. $= \frac{\pi D^2}{4} = 2\pi R (F + R)$

$$D = \sqrt{8R (F + R)}$$